AD-A139 637 FIELD STUDY ON MOISTURE PROBLEMS IN EXTERIOR WALLS OF FAMILY HOUSING UNIT..(U) TRECHSEL (H R) ASSOCIATES GERMANTOWN MD H R TRECHSEL ET AL. FEB 84 1/1

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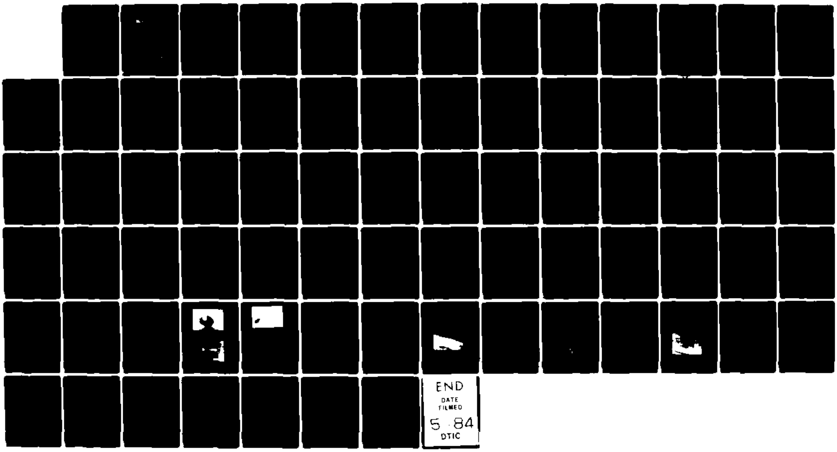

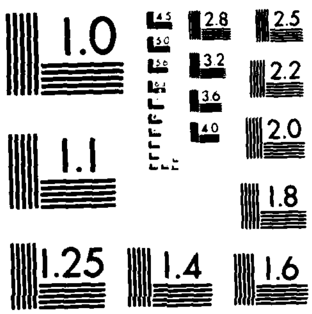

MICROCOPY RESOLUTION TEST CHART
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CR 84.022

NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

FIELD STUDY ON MOISTURE PROBLEMS IN EXTERIOR WALLS OF FAMILY HOUSING UNITS AT NAVAL AIR STATION PENSACOLA, FLORIDA

February 1984

An Investigation Conducted by
H.R. TRECHSEL ASSOCIATES
P.O. Box 211
Germantown, MD 20874

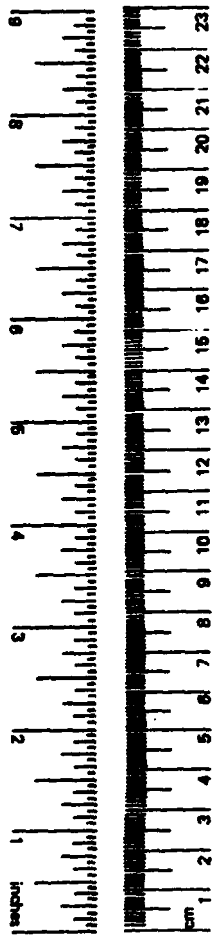
N62583/83-M-T063
N62583/82-M-T145

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

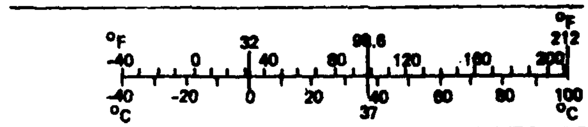
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Family housing units-Corry, Lexington Terrace & Townhouse; humid climate, masonry walls, moisture, condensation, air infiltration, water leakage, surveys, remedial measures, tests, relative humidity, mildew, ventilation, heating, cooling, vapor retarders, water proofing, coatings, energy conservation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes field studies and tests of water leakage, condensation, relative humidity, temperature and air infiltration related to moisture problems in exterior walls of family houses. Recommendations are provided for remedial measures, pilot test programs, and design/construction criteria leading to eliminating or reducing moisture problems.

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Acknowledgments

The investigation of the moisture problems in family housing units at the Pensacola Naval Air Station involved not only the collection of data and its analysis by the authors, but also the assistance of numerous others. Of greatest help was the untiring support and patience of Spencer Conklin of the Naval Civil Engineering Laboratory at Port Hueneme. He provided valuable liaison with NCEL and with NAS staff throughout the project, and coordinated the vital work conducted under contracts by others. John King and Ralph Tinsley, also of NCEL, provided valuable counsel and assistance in connection with the measurements of relative humidities, temperatures, air infiltration, and building air tightness.

Technical support from the Navy was provided by W. W. Reinschmidt, Director of the Engineering Division at the NAS Public Works Center, and O. H. Taffe, Jr., Manager of the Architectural and Structural Branch. J. J. Pastucha, Housing Director, N. C. Hansen, Director of the Family Housing Facility Management Division, and W. S. Kotich, Project Manager, all of the NAS Housing Office, provided effective liaison with the occupants, assisted with procuring necessary adjunct services, and in general helped "smooth the way" in many small but important ways. Also, J. Williams of the NAS Weather Station was most helpful in providing detailed weather data required for the analysis of the seasonal variations of observations.

The work under this contract could not have been completed without the help of other contractors, as well. P. Lagus of S-Cubed collected data on air infiltration; R. F. Miller conducted water leakage tests. J. Elder prepared and conducted the surveys. P. M. Campbell prepared the painting guide specification. In the latter, K. D. Callahan, A. P. Caputo, and R. E. VanLaningham, all of the National Concrete Masonry Association, contributed their extensive experience. Tests for moisture content and permeability were conducted by Pensacola Testing Laboratory, Inc. and Pioneer Testing Laboratory; Mary Reppert has edited the final report and Automated Words was responsible for typing and word processing. To all of the above, the authors express their sincere thanks and appreciation.

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1. EXECUTIVE SUMMARY

In various family housing units at the Pensacola (Florida) Naval Air Station, moisture damage and mildew growth have been reported. The problems seemed to occur primarily in Corry Field and Lexington Terrace. In the "Townhouse" units (on Base), the problems appear less severe. An attempt at Corry Field to correct the moisture and mildew problems through the installation of a vapor retarder on the concrete block wall between the furring strips did not cure the problem, and moisture problems persist in individual houses. Because of the above, the Navy Public Works Center of the NAS in Pensacola commissioned a preliminary investigation, consisting of a review of plans, a two-day field visit, the identification of possible causes, and the preparation of a general plan for developing specific corrective measures 1/.*

This report covers the results of a follow-up study started in August 1982 and completed in August 1983. It is the purpose of this study to identify the causes of serious moisture and mildew problems experienced in units of the NAS Corry Field and Lexington Terrace housing complexes, and to suggest remedial actions. The study consisted of extensive physical tests at intervals to approximate the four seasons, and of data gathering through surveys of occupants. Air infiltration and water leakage tests, and the conduct of the occupant surveys, were done by others under separate contracts, but H. R. Trechsel Associates was responsible for the correlation and analysis of all the test and survey data.

Most of the tests at Corry Field were conducted in one unoccupied house, although some tests were performed on a recently vacated unoccupied house, and on several occupied houses. All tests at Lexington Terrace were conducted in two unoccupied houses from August 1982 through November 1982. No additional tests were conducted at Lexington after November.

Brief visits were also made to Whiting Field, Milton, Florida, and to Tyndall Air Force Base, Panama City, Florida. It was found that the housing units at Whiting Field had apparently fewer moisture problems than similar units at Corry Field. Air infiltration tests indicated that the Whiting Field units had substantially higher air infiltration rates. The units at Tyndall appeared to be almost identical to those at Corry Field. Frequent moisture problems have been reported, but no quantitative analysis of the problems seems to have been made.

The overall program called for measuring temperatures and relative humidity of ambient air and air within wall cavities, air infiltration rates, and water leakage. Other data collected included moisture content of wall materials, water vapor permeance of interior finishes, wall surface and interstitial temperatures, and tests and observations relating to drainage of the ground adjoining the houses and to possible water seepage from the ground into the wall cavities. The occupant surveys were designed to establish the extent of the moisture problems, the types and locations of the problems, and possible occupant practices that could contribute to the moisture and mildew problems.

The surveys indicate that at Corry approximately 30 percent of all houses have moisture problems, and approximately 70 percent have moisture and/or mildew problems. Most of the problems were found in the bedrooms. At Lexington, 20 percent were shown to have moisture problems, and 28 percent had mildew problems.

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* Indicates references listed on page 35.

The results of the investigation suggest that in the Corry units rainwater and lawn sprinkler-water leakage into the concrete wall and through windows is a major, probably primary cause for the moisture problems. However, the failure of the walls in the test house to dry out when a rainscreen eliminated both window and wall leakage in one section of the test house indicates that capillary rise of ground water is also a probable cause of wetted walls. It is probable that inadequate wintertime ventilation of the bedrooms contributes to the moisture problems. In the Lexington Terrace units, some moisture problems appear to result from roof leaks. The roofs had been repaired relatively recently. Thus, any new problems which develop would be expected to be caused by other factors. One other contributing factor could be insufficient attic ventilation. Poor workmanship during reroofing, particularly with regard to flashing and caulking at roof penetrations, is another possible cause.

The mildew problems at Corry result both from poor wintertime ventilation of bedrooms and from inadequate summer humidity control. The mildew problems at Lexington result from general poor ventilation, and specifically from lack of positive bathroom ventilation.

Among remedial actions for Corry Field, the rehabilitation or replacement of windows, the sealing of cracks and the application on the exterior of "water-resisting" coating that does not develop hairline cracks, and upgrading of exterior wall maintenance, would reduce the incidence of the moisture problems in walls. Other desirable actions would be:

- Clean and seal joint between wall and footing and parge wall below grade, possibly install drain tiles at footing (if storm drainage can be provided).
- Install gutters and downspouts (reducing the amount of water deposited in the immediate vicinity of the house walls). Regrade site to provide better drainage.
- Provide additional wintertime ventilation.
- Balance heating/cooling system.
- Provide additional heat in the bedrooms.
- Install means for summer humidity control.
- Install automatic lawn sprinklers (controlled by management personnel).

Also, occupants should be reminded to turn on the exhaust fans whenever cooking or bathing/showering, and to keep bedroom doors open whenever possible (bedrooms have extremely low ventilation rates with doors and windows closed when the air-conditioning or heating are not running). During moderate temperatures in winter, windows should be opened frequently to provide additional ventilation, and sprinklers should not be operated so as to wet building walls.

For Lexington Terrace, the installation (and use) of bathroom exhaust fans would reduce the incidence of moisture problems in winter. Consideration should be given to the rehabilitation or replacement of the window subframes. The roofs, and particularly the flashing, should be checked and repaired as necessary. The attic insulation should be checked for adequacy and even distribution. The installation of gutters, downspouts, and splash blocks should be considered. Fresh air intakes for additional wintertime ventilation and whole-house fans for summer comfort and air circulation, and the balancing of the heat supply air system would be helpful in reducing moisture and mildew problems.

Because of the expense involved in implementing all the proposed measures, it is recommended that the major measures be applied to a few houses so that their effect can be evaluated and priorities can be established for the rest of the houses. However, for all exterior repainting, it is recommended that paints be used having a low water permeance (but high water vapor permeance), low shrinkage and good elasticity; and that as a general maintenance policy the joint between the aluminum windows and the ceramic tile stool be sealed and resealed periodically.

To eliminate or greatly reduce the potential for moisture and mildew problems in new buildings in the Gulf Coast climate, it is recommended that a water resistant (but vapor permeant) exterior wall finish be used. To prevent moisture from seeping into the walls below grade, concrete masonry units should be filled with mortar and parged, gutters and downspouts with splash blocks or connection to storm sewer should be installed, and attention should be given to grading to ensure good drainage away from walls. Consideration should be given to the installation of drain pipes around footings. Higher quality windows and careful installation are necessary to prevent water flow into the walls. For winter operation, adequate heat must be provided to all rooms, together with adequate ventilation (at least 0.5 ach). For summer operation, humidity control is necessary. Consideration should be given to the use of frame construction in lieu of concrete block masonry construction. Automatic in-ground lawn sprinkler systems (controlled by management personnel) could reduce impingement of sprinkler water on building walls and conserve water while providing adequate watering of lawns and landscaping.

2. INTRODUCTION

"Except for structural errors, about 90 percent of all building construction problems are associated with water in some way" 2/. The publication "Problem Definition Study of Requirements for Vapor Retarders in the Building Envelope" 3/ provides an overview of criteria, guidelines, codes, and standards currently in use. It discusses the state of the art regarding water vapor, condensation, and air leakage control, and indicates needed research and development efforts. That study also indicated a wealth of existing information on moisture control in cold and moderate climates, but a dearth of such information on warm and humid climates. Out of some 70 publications studied, the authors found only six which discuss the issue of moisture control in warm and humid climates. Four of them 4, 5, 6, 7/ discuss the issue only or primarily as related to air conditioning and indicate solutions requiring the selection of appropriate equipment to lower the indoor air relative humidity. Only one 8/ discusses in depth the issue of moisture and mildew control in unair-conditioned buildings in warm and humid climates.

A brief field visit to Pensacola in the spring of 1982 1/ indicated serious moisture problems. The problems of prime concern were those where interior gypsum wallboard was moist to waterlogged (Corry Field) and plaster and paint deteriorated (Lexington). According to Base personnel, the replacement of wallboard, where necessary, adds an average of one day to the turnaround between occupants. In Lexington Terrace, many of the problems also occurred in bathrooms, which have windows but no mechanical ventilation. Substantial mildew problems were also reported. These occurred both on walls and in furnishings, such as on mattresses of beds placed against walls and in rugs. The visit did not uncover a clear-cut cause of the moisture problems. However, condensation as a direct result of air conditioning in summer did not appear to be the only or even the most significant cause for the moisture problems, as moist and waterlogged gypsum wall board were in evidence during the visit in an unoccupied house (Corry 2364 B) in early April, with the air conditioning turned off for some time (probably since the fall of 1981). Accordingly, in this study all likely causes were investigated.

A first priority was to determine where the moisture in the gypsum board and plaster originated—essentially, did it originate from the indoor habitable space or from the concrete wall and the outdoors? If from the wall, how did the humidity get into the wall, and what is the mechanism for transporting the moisture into the wall and from the wall into the gypsum board? The tests and analysis described in the following sections were designed to provide answers to these questions.

The original intent was to study both the Lexington Terrace and the Corry Field dwelling units with equal priority. However, because the Corry Field units are newer and constitute a greater investment, and replacement of the gypsum board is more costly in Corry than the repainting of Lexington plaster walls, the study did emphasize the Corry housing units. Accordingly, the discussion of tests, results, conclusions and remedial actions are discussed first for the Corry Field units. Lexington Terrace is discussed in a separate chapter at the end of this report. A brief chapter also covers the townhouse development of the NAS.

3. DESCRIPTION OF HOUSING UNIT (CORRY FIELD)

All Corry Field units are three-bedroom, 1 1/2-bath semi-detached one-story houses with a rather large living room and kitchen/dinette combination. Each unit also has a carport. There is provision for a dryer in the kitchen, with an outside exhaust opening. Both kitchen and baths have exhaust fans. The bathroom fans can be operated only when the light switch is on, but the light switch does not automatically operate the fan. Construction is exterior exposed concrete block walls with 2 inch (nominal) furring, 1 inch cellular board (expanded polystyrene) insulation, and gypsum board finish, as shown in Figure 1. The gable roofs have soffit ventilation and gable vents. Ceiling insulation is 6 inch with a vapor retarder. Each dwelling unit is served by a gas central hot-air heating system using outside air for combustion, and an electric central air conditioning system. The houses contain about 1200 square feet of floor area and an outside storage room. The houses were built about 1972.

A previous effort was made to eliminate the moisture problem. The existing gypsum board and fiberglass thermal insulation were removed, a coating applied to the concrete block wall between the furring strips, and new expanded polystyrene board thermal insulation and new gypsum board were installed. The purpose of the coating on the concrete block wall was to act as a vapor retarder to reduce the moisture flow from the concrete block into the insulation and the gypsum board. Two types of coatings were used: a clear sealant and a black asphaltic coating. The quality of the clear sealant application could not be determined, but in one house (No. 2398 A) an inspection of several segments of asphaltic coated wall indicated that the application of the coating left many pinholes open. Since the coatings were applied only between the furring strips, moisture could of course still enter at the locations of the strips. In any case, the previous effort did not eliminate the moisture problems, although no data are available to indicate whether and if so, to what degree, the coatings did ameliorate the situation.

4. EXPERIMENTAL WORK (CORRY FIELD)

Discounting active roof leaks, for which no evidence was found, there are five basic possible causes for the observed moisture problems:

- Rainwater and sprinkler-water leaks through masonry or at windows.
- Rising damp from water leakage at the footing.
- Condensation of moist indoor air in winter or moist outdoor air in summer.
- Inadequate ventilation and heat in winter.
- Inadequate summer dehumidification.

It is probable that the problems are caused by more than one of the above causes. To estimate the causes, or to identify the contribution of individual causes, a series of tests, observations, and surveys was devised. These were conducted in September, November, January, February/March, and in May. They thus covered essentially all seasons.

The tests and observations consisted of measuring air temperatures and relative humidities indoors, outdoors, and within wall cavities, and surface temperatures (exposed and interstitial); determining moisture content and water vapor permeance of wall materials; measuring of air infiltration (by others under separate contract); observations of drainage patterns on the site and water seepage into walls below grade; water-spray tests at windows and masonry wall segments (by others under separate contract); and the conduct of occupant surveys to determine occupant practices and extent and location of moisture problems (by others under separate contract). While the other contractors report directly to the NCEL, a synopsis of their reports and findings are included in this report. In this section, all the test procedures and arrangements are discussed. The test results are given and discussed in the next section.

4.1 Temperatures and Relative Humidities

The temperatures and relative humidities were measured inside the house, out of doors, and within several of the wall cavities. Therefore, indoor, outdoor, and wall cavity readings were taken over a period of one-half to two hours. During the first series of tests it was attempted to take temperature and RH readings at regular 6-hour intervals during the 24-hour day. This was later discontinued as unnecessary. It appeared that readings twice daily, approximately during the hours of highest and lowest temperature, were sufficient.

The instrument used was Humicap HMP 15 Piercing Probe and Humicap HMI 31 Digital Indicator. The instrument was periodically calibrated with the Humicap HMK 11 Probe Calibrator. All Humicap instruments were manufactured by Vaisala of Helsinki, Finland, represented by Vaisala, Inc., 22 Cummings Park, Woburn, MA 01801. Figure 2 shows the probe and indicator; Figure 3 shows the probe inserted into the calibrator. The probe gave reliable service, except that in saturated air the readings exceeded 100 percent RH. This is attributed to condensation forming on the sensor itself. Inaccuracies above 99 RH percent are irrelevant to the conclusions.

For measuring the temperatures and relative humidities within concrete block cavities, a hole was drilled from the building interior into the block cavity wall with a slow speed drill. The hole diameter was slightly larger than the diameter of the probe. A larger hole also was drilled through the gypsum board and the insulation board. Figure 4 shows the finished hole, and Figure 5 shows the probe inserted into the hole. When the probe was not inserted, the hole in the block was sealed with a cork stopper, and the hole in the gypsum board covered with tape.

The temperature and moisture measurements were taken in walls with and without a rainshield. The rainshield was constructed of 2x4 framing with polyethylene sheeting. The rainshield was approximately two feet in front of the wall and had openings of several inches top and bottom to allow air currents. Figure 6 shows the rainshield at Corry Field No. 2363 A. The rainshields were subject to deterioration or vandalism, and were not entirely effective during the later part of the test period.

The probe locations (Stations) are shown on Figures 7 and 8. Probes 1, 2, and 3 were the original locations (2 and 3 having both a high top and a low bottom location). Probes 4 (also top and bottom) and 3 A, B, and C were added later. Because both temperature and RH were virtually identical for the top and bottom Stations, the bottom Stations for 2, 3, and 4 were discontinued after an initial number of readings. Stations 1 and 2 were behind the rainshield. The wall outside probes 3 and 4 was exposed to the weather.

4.2 Moisture Content of Wall Materials

In September, November, and February, wall material samples were collected and analyzed for water content. The tests for September and November were conducted by Pensacola Testing Laboratory, Inc. The February tests were conducted by H. R. Trechsel Associates. The tests were conducted by oven drying samples at approximately 180°F until a constant weight was obtained.

Concrete block inside-flange and gypsum board samples from Stations 1 and 4 were analyzed in September for moisture content. In November, additional samples were tested: near Station 1, samples were collected from the gypsum board and both the outside and inside flanges on the concrete block, allowing the establishment of a moisture profile through a wall behind the rainscreen; and from near Station 2 (gypsum board only), also behind the rainscreen. Near Station 3 a series of samples was taken high in the wall: one sample of concrete block each from the outside flange, from the webb, and from the inside flange; and from the gypsum board, allowing the establishment of a moisture profile through a wall exposed to the weather, that is not behind the rainscreen. Samples were also taken of gypsum board and of the interior flange of the concrete block directly below the above samples near Station 3. This was to provide information regarding the possible stratification of moisture within the wall. Another sample of gypsum board was taken near Station 4.

4.3 Air Infiltration Tests

Tracer-gas dilution tests were conducted by S-Cubed of La Jolla under a separate contract with NCEL 9/. S-Cubed is providing their own detailed report. In this report only a synposis of the test results is provided. All tracer gas tests were conducted in accordance with ASTM E 741-80 and its revision, currently being balloted in committee. The tracer gas used was sulfur hexafluoride (SF_6).

The tests included both whole-house infiltration tests and tests in the bedrooms, both with doors open and closed. In the bedroom tests, the tracer was released into the furnace return air intake when the equipment fan was operating. The fan was then shut off prior to and during the sampling in the bedrooms. In addition, container sample tests were conducted in 25 selected occupied houses. The latter tests were to be used to determine the correlation, if any, between houses which exhibited certain air infiltration characteristics and a high incidence of moisture problems. For these container tests, the tracer was also released into the return air intake while the fan was running. The fan was shut off just prior to the first sample and remained off during the test.

4.4 Ground Drainage Tests and Observations of Standing Water During Rain

The normal water table at Corry had been previously investigated by Public Works personnel and found to be several feet below grade. However, some question remained as to how fast water would drain during and after a heavy rain. Therefore, a simple test was devised. This called for flooding the ground with a garden hose, discontinuing the water supply, and measuring the rate of drainage by means of a dipstick in a perforated pipe sunk into the ground. This test was conducted in November. The test was conducted twice: in the first test water was supplied for one-half hour to simulate a short rain. In the second test, water was applied for approximately 12 hours, simulating a long-lasting rainfall. No effort was made to measure the water supplied in either test.

On February 28, 1983, a heavy rain provided an opportunity to observe the drainage patterns of the ground around some of the houses. The rainfall on that date was recorded at the nearby air station as 2.41 inches. (During all of 1982 and the first two months of 1983, this level of daily rainfall was exceeded only twice—on June 27, 1982 with 4.14 inches and on July 30, 1982 with 2.65 inches.) The pattern of standing water was drawn on prepared schematic drawings of the houses. The houses were selected based on the results of the occupant survey so that about half the houses observed had moisture problems.

4.5 Water Leakage Observation at Footing

Because of a concern that water might leak into the concrete block cavities below grade, two approximately 10-foot trenches were dug in January along the wall and footing outside of Stations 1 and 3. One of the trenches was behind a rainscreen, and the other was not. The trenches were approximately 1 foot deep and 14 inches wide. The trenches exposed the footings and the block wall below grade (Figure 10). The wall and footing were then well cleaned, of dirt and loose debris.

At two locations (Stations 3C and 3D), water was inserted into the wall cavities through ports drilled into the block from inside the house to observe whether it would drain out at the joint between footing and wall. During rain, the level of water in the trenches was observed and the rate of drainage noted.

The footing and wall below grade were then cleaned again, loose mortar was chiseled out, and the joint between footing and wall patched as needed to provide a smooth and clean surface. After drying (using a heat lamp and a gas torch), a heavy coat of asphaltic waterproofing material was applied to the top of the footing and the wall up to about 2 inches above grade, and the trenches re-filled. Relative humidity readings were taken in the wall cavities at the trenches (Stations 1 and 1A, and 3C and 3D) before digging, during the period when the trenches were open, and after parging and waterproofing.

4.6 Water Spray Tests

Because moisture problems appeared to be more frequent in the vicinity of (particularly below) windows than in windowless walls, and because visual inspection indicated deficiencies in glazing gaskets and weatherstripping, an initial water-hose test was conducted in November and repeated in February. That test consisted of randomly directing the full stream of a garden hose against the window and its frame and observing water leakage on the inside. The test was conducted on the windows of the smaller bedrooms.

To investigate the potential of water wetting the concrete block through hairline cracks in the deteriorated paint finish, the absorption of water at the hairline cracks was tested in February by depositing drops of water with an eye dropper at the cracks and observing capillary action, if any.

These "pilot" tests were then followed in May with tests conducted by Architectural Testing, Inc. of York, PA, under separate contract to NCEL. This series of tests was conducted according to ASTM E 331, modified for field application. The apparatus used for the water spray was a spray grid calibrated by the contractor at his laboratory according to E 331, to deliver 5.0 gal/ft^2.hr over the entire test area. During the test, the time to leakage and the type of leakage were recorded. The test was conducted on two windows of Corry house 2363 A and on two windows of Corry house 2399 B. The tests were started at zero indoor/outdoor pressure differential. The pressure was then set at 0.10 inch and raised to 0.3 inch. The pressure was maintained across the test area by means of a "fan door." For the test, all gypsum board and insulation were removed below and at the jambs of the window so that water penetration through the wall, if any, could be observed.

The same tests were also conducted on two windowless wall areas in house 2363 A and on one wall area in house 2399 B. All gypsum board and insulation were stripped from wall areas (approximately 6 feet wide and room height), so that any leakage or moisture seepage could be observed. In addition, viewing ports were cut into the concrete block from the house interior to give access to the block cavities.

4.7 Occupant Surveys

A total of three occupant surveys were conducted. Two, covering a total of 80 dwelling units, were conducted by a contractor under separate contracts with NCEL. A third, covering 6 houses, was conducted through NAS Public Works personnel.

The purpose of the two larger surveys was to:

- Establish the extent of the moisture and mildew problem in NAS housing units.
- Identify the location and type of problems.
- Identify houses with and without problems so that a) air inflitration tests could be conducted in an effort to establish a correlation between infiltration rates and problems, and b) a visual observation of drainage patterns around buildings could establish additional correlations.
- Determine occupant behavioral and HVAC equipment management patterns that might point to correlations with the incidence of moisture problems.

The first survey was conducted in September 1982, and covered 26 dwelling units 10/. The second survey (February 1983) covered 54 units and used a questionnaire that was revised based on the experience with the first survey 11/.

The third survey (April 1983) was conducted to obtain data on the incidence of moisture problems in five specific houses which had been found to have a serious drainage problem, and which had not been included in the two earlier surveys. A much simplified questionnaire was used in this survey.

4.8 Additional Observations

While the above nine items constitute the major efforts in determining the causes of the moisture problems at Corry Field, other studies were undertaken that either proved inconclusive or were not of the rigorous technical nature that would qualify them to be given prominence in this report. The additional studies involved a sprinkler test, saturation of the ground, moisture probes in occupied houses, and visits to Whiting Field and to Tyndall Air Force Base.

4.8.1 Sprinkler Test. A lawn sprinkler was installed outside of Station 3 and run over a two-day period. During this time, the water-resisting performance of the window near Station 3 was observed and the temperatures and relative humidity in the concrete block cavity were measured at Station 3.

4.8.2 Ground Saturation. Using a water hose, the ground was saturated over a two-day period outside of Station 4 and the temperature and relative humidity of the air inside the concrete block cavity measured in Station 4.

4.8.3 Moisture Probes in Occupied Houses. In two occupied houses which exhibited moist or water-saturated gypsum board on outside walls (one below a window, one on a wall without window, both in bedrooms), the temperatures and relative humidity were measured within the concrete block cavity at the location of the moisture problem.

4.8.4 Surface Temperatures. Surface temperatures were measured only in November and May and only at Stations 1 and 3. The temperature was measured at the indoor and outdoor exposed wall surfaces, at the indoor face of the concrete block, and at the two faces of the wall cavities. Figure 9 gives the probe locations.

The surface temperatures were measured with a Barnes Model 33-100 Platinum Thermometer with surface probe, calibrated by the National Bureau of Standards.

4.8.5 Permeance of Interior Finish At each of Stations 2 and 4, two samples of gypsum board with the paint finish were taken. Also, two samples of a control board without the finish were cut from a board stored in the house. The six samples were tested for permeance according to ASTM E 96-80 by Pioneer Laboratory, Inc. of Pensacola.

4.8.6 Visit to Whiting Field. During a visit on May 16, 1983, to Whiting Field, two houses were inspected. It had been reported that little moisture damage existed in these houses which were built similar to those at Corry Field. Also, air leakage tests were performed by S-Cubed on one house.

4.8.7 Visit to Tyndall Air Force Base. On May 19, Tyndall Air Force Base was visited to inspect two houses built similar to those at Corry Field. The houses at Tyndall AFB had been reported to exhibit rather severe moisture problems.

5. RESULTS AND DISCUSSION OF EXPERIMENTS (CORRY FIELD)

5.1 Temperatures and Relative Humidities in Cavity of Concrete Blocks

The temperatures and relative humidity measured in the cavities of the concrete block used in the wall construction provided information on the warming effect of the sun on the walls of the house and the resulting influence on moisture movement in the wall, when these measurements were compared with the indoor and outdoor temperatures and relative humidities. An ASHRAE Psychrometric Chart was used to determine the dew-point temperatures corresponding to the various sets of dry-bulb temperatures and relative humidity, since the dew-point is the best measure of the vapor pressure and the direction of movement of moisture by diffusion within a building contruction.

Table 1 shows the dry-bulb temperatures and the dew-point temperatures at Stations 1, 2 and 3 and indoors and outdoors at several times of day during the period September 17-19, 1982, when summer conditions prevailed. The dry-bulb cavity temperatures were higher than either the indoor or outdoor temperature most of the time from before sunup to after sundown. This is attributed to the warming of the concrete block by the sun during the day and the heat storage effect of the concrete block during the night. Exceptions to this relationship between cavity and outdoor temperature occurred for about one-third of the observations, mostly before the sun struck the outside wall in Stations 1, 2, and 3. The principal exception to this relationship between cavity and indoor temperature occurred at Station 1 at 6 am before sunup.

More often than not, the dew-point temperatures in the concrete block cavities were significantly higher than either the indoor or outdoor dew-points and in some cases higher than the indoor and outdoor dry-bulb temperatures. In some cases the air in the cavity was saturated at a temperature higher than either the indoor or outdoor temperature. This strongly indicates that the concrete block contained moisture that was evaporated by the solar heat to produce dew-point temperatures in the cavity above the indoor and outdoor temperatures. When these conditions existed, water vapor would be moved both toward the indoor and outdoor by diffusion, and since the temperature of the insulation and/or the gypsum board on the inner side of the concrete block would typically be below the cavity dew-point temperature, condensation would occur on these materials. Based on the data in Table 1, the conditions for condensation on the insulation and gypsum board existed from 12:30 pm until 10:30 pm on September 17 at Stations 1 to 3, and at some stations from 9:30 am to 10:30 pm on September 18. Before sunup on September 17 and 18, the dew-point temperatures of the insulation and gypsum board may have been slightly higher than the cavity dew-point temperature, in which case some condensation could have been re-evaporated and re-absorbed by the concrete block. These moisture conditions existed in the concrete block even though the rainfall during the first half of September was approximately half the normal rainfall for Pensacola, and both Stations 1 and 2 had been protected by the rain screen since August 27. A summary of the rainfall data from June 1982 to February of 1983 is given in Table 2. Average weather data for Pensacola are given on Table 3.

Table 4 shows similar dry-bulb temperature, relative humidity, and dew-point temperature data at five stations in the concrete block cavities, indoors and outdoors, for the period January 17 to 20, 1983, when winter conditions prevailed. During the winter period the outdoor temperature ranged from 42°F to 57°F. The cavity temperatures, except for all Stations on January 17, were between the indoor and outdoor temperatures in both clear and rainy weather. Except for Station 2, on January 18 and 20, the dew-point temperatures in the concrete block cavities were always higher than the indoor and outdoor dew-point temperatures, which indicates that the concrete block still contained moisture. However, condensation probably did not occur on the insulation and gypsum board during the period January 18-20 because their temperatures were probably higher than the cavity dew-point temperatures.

Temperatures and relative humidities were also observed in the concrete block cavities and indoors and outdoors during the period February 18 through March 2, 1983. Outdoor temperatures were in the range 41°F to 52°F on February 26, but more typically in the early spring range of 55°F to 67°F during the remainder of this period. Table 5 presents the data for February 25, when the outdoor temperature ranged from 52°F at 9 pm to 63°F at about 2 pm, and the weather was sunny. During this period water was being evaporated in the house at a rate to simulate an occupancy of four persons, causing the indoor relative humdity to be in the range from 62 to 76 percent.

On February 25, when the outdoor temperature ranged from 52°F to 63°F, the dew-point temperatures in the cavities were always higher than the outdoor dew-point temperatures, indicating that moisture would be moving toward the exterior of the house. During most of the day the cavity dew-point temperature was higher than the outdoor dry-bulb, indicating that condensation would occur in the exterior shell of the concrete block. Furthermore, the dew-point temperatures at Stations 1 and 1A from 10:30 am to 4:30 pm were higher than the indoor dry-bulb temperature, indicating that condensation would be occurring on or in the insulation and gypsum board. The indoor dew-point temperature was equal to or higher than the cavity dew-point temperatures during the forenoon at Stations 2, 3, 3C, 3D and 4, but the reverse was typical in the afternoon when the sun shone on the walls at these stations. The indoor dew-point temperatures were only marginally above the cavity dry-bulb temperatures for a short time around 11 am on February 25 at Stations 3, 3C, and 3D, indicating that condensation in the concrete block caused by diffusion of indoor moisture was minimal. These observations indicate that the moisture was moving back and forth in the wall at different times of the day, and causing condensation under certain conditions and leaving the wall entirely at other times. At Stations 1, 1A, 3, 3C, 3D and 4 the relative humidities in the concrete block cavities were near saturation throughout the day.

Prior to conducting the water spray tests on May 16, 1983, one set of readings was taken to indicate the conditions that might exist during later spring. The results of this test are shown on Table 6. During that reading, the dew-point temperatures in the cavities (with one exception) were higher than the outdoor and indoor dew-point temperature, indicating that moisture would be moving toward both the exterior and interior from the concrete block cavity.

Table 7 gives an overview of the seasonal swings of dry-bulb, relative humidity, and dew-point temperatures indoors, within the concrete block cavity, and outdoors. It will be noted that except for the period of November 16-19 (when the outdoor dew-point was one degree higher), the dew-point temperature within the block cavity was higher by 4 to 25 degrees than either the indoor or outdoor dew points. It will also be noted that the outdoor dew-point temperature was higher than the indoor dew-point temperature in September and November, but that then a reversal occurred and the indoor dew-point temperature was higher than the outdoor temperature, but below the cavity dew-point temperature in January, February, and May.

The totality of the temperature and relative humidity observations in the cavities of the concrete block and indoors and outdoors strongly indicates that there was always enough moisture in the concrete block to allow the sun's heat to raise the dew-point temperatures above the indoor and outdoor dew-points and frequently above the indoor and outdoor dry-bulb temperatures. Thus the condensation observed in the insulation and the wetting and softening of the gypsum board is attributed principally to the effect of the sun's heat on the concrete blocks that seldom, if ever, dry out.

5.2 Moisture Content of Wall Materials

The moisture content of wall materials was measured to provide information on:

- o Actual moisture content.
- o Change of moisture content due to the installation of the rainscreen.
- o Moisture content as a function of time.
- o Distribution of moisture through the wall from the outside to the inside.
- o Distribution of moisture vertically in wall.

The results of the tests are given on Table 8. An examination of the values shows that the concrete block contained from 2.3 to 10.3 percent water by weight, and the gypsum board contained from 0.5 to 35.2 percent of water by weight. The larger variations, although partially spread over time, indicate a relative local distribution of very high and very low moisture content of wall materials. This would indicate that the source of moisture or the mechanism of its transport is also localized and suggests that either leakage of liquid water or leakage of moist air are primary sources of the moisture in the materials.

In location 1, the moisture content in the concrete block behind the rainscreen decreased from 6.4 percent in September to 4.7 percent in November. No September data on the moisture content of concrete block are available for the exposed wall, e.g., walls without the rainscreen. However, November values of between 8.6 and 10.3 percent were observed on samples taken from the inside face of the concrete block; in close-by locations, values of 2.3 to 8.5 were measured in January. Thus, while behind the rainscreen the moisture content declined substantially from September to November, in the areas not protected by the screen, the concrete block experienced a lesser decrease in moisture content from November to January.

The moisture content of gypsum board also was determined. Measured values were 15.3 percent in August, 13.25 to 35.2 in September, 0.5. to 17.5 in November, and 12.8 in January. The reasons for the observed moisture pattern are not obvious.

5.3 Air Infiltration Tests

Data collected by S-Cubed in November 1982 9/, are summarized in Table 9. Additional container test results on occupied houses are shown on Table 10. These latter tests were conducted to investigate the possible correlation of infiltration rate with identified moisture problems. Reference is made to Table 16 and to discussion under 'Conclusions' regarding the findings.

In general, the air leakage rates were found to be very low with the furnace fan off—ranging from close to zero in individual bedrooms with doors closed to 0.1 air changes per hour (ACH) in bedrooms with doors open. An infiltration rate of 0.2 ACH for the whole house was observed in the unoccupied Corry #2363 A, with the fan running (see Table 11). In occupied Corry units, the measurements showed levels of 0.16 to 0.53 ACH (see Table 10). Assuming a family of four, this would correspond to a ventilation rate of 6.4 to 21.2 cfm per person. (ASHRAE Ventilation Standard 62-73 establishes a minimum of 5 cfm per person.) But note that these rates are for the house as a whole. If only the bedrooms are considered, the 0.1 ACH measured in Corry 2363 A with open doors would result in only 1.3 cfm total, or with two people in the room, in only 0.67 cfm per person. (The situation with doors closed would be even worse.) Appendix 1 provides calculations on required ventilation rate to control relative humidity in winter. The calculations show that approximately 0.5 air changes per hour are required in the Pensacola, Florida climate.

5.4 Ground Drainage Tests and Observations of Standing Water During Rain

The results of the drainage tests conducted in November are given on Table 11. The tests showed that the sandy ground drained well after the simulated short rains, and drained to a level below the top of the footing in about one and one-half hours after the simulated 12-hour rain. However, in both tests the surface of the ground showed some standing water during the one-half and 12-hour period when water was supplied, correlating well with the results of the observations made in February.

The observations in February during and after the heavy rain showed that out of 20 houses observed, 12 showed substantial standing water at or near the house walls, 6 showed moderate amounts of standing water, and only 2 showed no standing water at all. The correlation, or lack thereof, of these observations with reported moisture and mildew problems is discussed below, in Section 6 on conclusions. Figures 12 and 13 show samples of the results of the observations. Figure 12 shows a house classified as having "heavy" standing water, and Figure 13 one classified as having a "moderate" amount of standing water.

By comparing the standing water observed on February 28 with the water level observations taken when the ground was flooded with a garden hose, it appears probable that the water level during this rainstorm was above the footings for several hours for many of the houses.

5.5 Water Leakage Observation at Footing

Shortly after the trenches were dug, rainfall on two days (January 19, 0.62 inch, January 20, 1.28 inch) filled the trenches to above the original grade level. They drained partially only after more than an hour, thus confirming the findings of the drainage tests conducted in November (Table 11). The trench at Station 1, behind the rainscreen, filled equally as fast as the trench at Station 3 without rainscreen. After the trenches were dug, the footing and wall below grade were exposed to air between rainfalls, but this did not result in a lowering of the relative humidity of the air inside the affected wall cavities over the period from November to February.

Moderate amounts of water introduced into the wall cavities in two locations in the same block cavities as stations 3C and 3D drained to the outdoors at the bottom of the concrete block wall. Thus it was proved that water also could enter the wall cavities from outside, whenever during rain the water table is temporarily above the footing.

After applying a waterproof coating to the footing and wall below grade, the relative humidity inside the wall cavity did not change over the period from early March to mid-May.

* Indicates references listed on page 35.

It could be expected that the wall would have experienced a drying out after the trenches were dug, if the water could have been kept out of the trenches and the test period had extended over a longer period. Similarly, the application of the waterproofing will probably result in a drier wall after several months or years. However, neither of these conditions could be met within the scope and time frame of this study.

5.6 Water Spray Tests

5.6.1 Water Pilot Tests. In the initial water-hose test in November it appeared that water leaked not only through the window itself, but also into the block wall. Similar results were obtained in February. During both November and February tests, it was found that water leaked into the wall below windows in three modes: in the first, the water leaked both through the weatherstripping and around the glazing gaskets, overflowed the interior sill of the window channel onto the ceramic tile stool, and leaked by capillary action into the joint between the aluminum window frame and the stool. Figure 14 shows this leakage path. The second path followed the first through the window, but the water leaked into the wall from the sill at the window corner and at the jamb where the tile grout had deteriorated. The third leak was observed on the interior at a lower corner of the precast window sill. The origin of this leak could not be determined.

The careful caulking at the interior of the joint between the window frame and the tile stool, and the patching and caulking of the joint between the jamb and the stool, appeared to block the leakage at these points and to stop the leakage into the wall, although window leakage continued and water continued to flow over the stool and down the interior face of the wall below the window.

The aluminum screen frame blocked the water flow from the weep holes in the window channels. This contributed to the overflow of the window channel, and after the screen frames were notched, the amount of overflow decreased substantially.

The eye-dropper water tests of capillary action at hairline cracks in the deteriorated paint showed that most cracks "took in" water. Thus moisture can enter the concrete blocks even if neither air nor water pressure are present.

5.6.2 Modified ASTM E 331 Tests. The test results were reported directly to NCEL by the contractor conducting the tests, Architectural Testing, Inc. The results are summarized here.

The tests on the windows essentially corroborated the results of the water-hose tests. Substantial window leakage was observed at the same places as in the earlier tests. It was also found that the water, after leaking through the windows, found its way into the wall below, specifically into the space between the insulation board and the concrete block. The gross water leakage is attributed by the testing agency to loose glazing at fixed lights, weather-seal shrinkage, deteriorated sill corner sealant, and to lack of proper sill drainage.

During the tests on the solid masonry walls, water leakage into the concrete block cavity was observed. In one instance (corner of Corry 2363 A) the concrete block cavity filled up to a level 12 inches above the exterior grade and some 18 inches above the footing, and a small amount of water flowed from underneath the baseboard onto the floor. On the NW corner of 2363 A, moisture became apparent on the inside at the mortar joints. In another case (SE corner of Corry 2399 B) water was seen dripping inside the concrete block cavity. In that same location, the insulation board, when removed prior to the test, was wet on its exterior (the side facing the block wall). This condition was identical to that observed on Corry 2363 A during the initial visit on April 3, 1982 1/.

The tests indicate that the source of the moisture within the concrete wall cavity could be outside rainwater infiltrating through the window and through the block exterior.

5.7 Occupant Surveys

The two major surveys were conducted under a separate contract and the results have been reported by the contractor to NCEL 10, 11/. The results are summarized here, and include the five houses of the third survey conducted by NAS personnel.

Of the 200 dwelling units at Corry Field, a total of 85 houses were surveyed. Of this sample, 26 (31 percent) had current, past, or potential moisture problems and 41 (48 percent) had mildew problems. A total of 56 houses (66 percent) had mildew or moisture problems, or both, and only 29 (34 percent) had neither moisture nor mildew problems.

Of 28 clearly identified individual moisture problems, 26 (93 percent) were in bedrooms, and 2 (7 percent) were in kitchen/dinette spaces. No problems were found in living room walls. (Problems in bathrooms and mechanical rooms which were not related to exterior walls are not included in these numbers.)

Of the 28 moisture problems, 17 (61 percent) were under or next to windows, and 11 (39 percent) were either on walls without windows, or were at some distance from the window.

Of the 11 problems not near a window, 2 (18 percent) were leaks below baseboards, 4 (36 percent) were problems along wall/ceiling joint, 2 (18 percent) low in corners, and 3 on blank walls near neither ceiling, corner, or baseboard.

Several occupants mentioned that the moisture problems appeared, or worsened, after substantial rainfall. Several also complained about cold bedrooms in winter.

According to the two larger surveys which included the necessary data, there were essentially no differences between homes with moisture problems and those without. In both groups, about two-thirds of the homes had mildew problems. Thermostat settings were similar, as was the use of air conditioning and natural ventilation. Exhaust-fan use was about the same. No homes with moisture problems had aquariums; eight with no moisture problems had aquariums. The presence of house plants was similar for both groups. The incidence of water from sprinklers touching outside walls was almost equal. Almost all the occupants in both groups noted that in winter condensation forms on the inside of windows. Discoloration of outside walls occurred both where moisture problems existed and where they did not. Likewise, not all outside areas corresponding to interior moisture problems exhibited outside discoloration. Occupant complaints of cold bedrooms in winter, and of condensation on window glass during cold weather also were received apparently independent of whether the houses had or had no moisture and/or mildew problems.

5.8 Results of Additional Observations

5.8.1 Sprinkler Tests. The window near Station 3 in Unit 2363 A did not leak appreciably during the sprinkler test, although during the two days of tests, a small quantity of water did overflow the sill. Wind speed or direction was not measured, but at no time was the wind estimated to exceed 5 mph.

A summary of the measured temperature and humidity during the sprinkler tests is shown on Table 12. An examination of the table shows that while the average relative humidity within the wall cavity increased from 91.1 to 94.3 from the dry wall to the wall wetted by the sprinkler, the dew-point within the cavity actually declined from 69.5 to 64.5°F. It appears that the rise in relative humidity may be more attributable to the cooling effect of the water spray than to the diffusion or infiltration of water.

5.8.2 Ground Saturation. The results of the ground saturation test near Station 4 are summarized in Table 13. The table shows that relative humidity and dew-point temperature increased from 89.5 to 91.6 percent and from 69.5 to 72°F, respectively. These rises are consistent with those obtained during the water-spray tests later conducted by Architectural Testing, Inc.

5.8.3 Moisture Probes in Occupied Houses. The relative humidity in the wall cavities in both occupied houses was consistently at or very near saturation (99 to 100 percent), and resemble therefore the measurements taken in the test house (Corry 2363 A) at Stations 1, 3, and 4.

5.8.4 Surface Temperatures. The results of the surface temperature tests are shown on Table 14. The measurements were taken in November and May. During both periods temperatures indoors and outdoors did not differ by more than a few degrees F. Accordingly, the surface temperatures of the concrete block also did not differ substantially from these temperatures, except when the sun was directly impinging on the block (location No. 1 on May 16). The data did not indicate any significant conclusions relevant to moisture.

5.8.5 Permeance of Interior Finish. The results of the tests are given in Table 15. The results indicate that the painted gypsum board samples (#2 and #4) tested had a very high permeance, in other words, a low resistance to water vapor diffusion. According to the test results, the interior finish would not in a substantial way hinder the passage of moisture from the wall into the building interior. However, the samples were not taken from wall areas with actual and substantial moisture problems. The relatively high permeance of the finish in these areas may be precisely part of the reason why no apparent moisture problem existed in the particular location. This may specifically apply to Location 4, which showed high relative humidities and dew-points within the concrete block cavities, but did not exhibit a moisture problem in the wall.

The results differ widely from published data 4/, and it is suggested that the existence of an error in the laboratory work is not to be ruled out, and these data should not be given great weight in the analysis.

5.8.6 Whiting Field. The houses are constructed similarly to those at Corry Field, except that the walls do not contain thermal insulation. Two houses were inspected at Whiting Field. Both showed moderate moisture problems (compared to those found at Corry Field), but no data were made available which would allow a comparison of the extent of the problem between the two complexes. The air infiltration tests conducted by S-Cubed are being reported separately, but infiltration rates in the order of 1.3 ACH were measured. This is more than twice the rate of the Corry house with the highest leakage rate, and almost ten times the rate of the Corry house with the lowest leakage rate.

5.8.7 Tyndall AFB. The houses inspected at Tyndall AFB appear very similar to those at Corry, with regard to construction and plan layout. However, the windows appear to be of better quality. They also appear newer, which would imply that they were replaced at one time, since the houses themselves are older than those at Corry.

No actual moisture problems were observed, although two vacant houses had just been repaired by maintenance. Also, no data on the extent of moisture problems were made available. The Air Force is currently undertaking a major energy retrofit program, in which the air tightness of houses is being measured with a fan door. If and when these data are made available, they will indicate whether the Corry houses are abnormally tight compared to similar housing in other services.

6. CONCLUSIONS (CORRY FIELD)

In Section 5, the discussion was restricted to the individual test results and observations. In this section, the tests will be related to one another.

The most significant findings were the results of the dew-point relative humidity and temperature measurements, the water-spray tests, the air infiltration tests, and the surveys. Calculations show that, except for some days in January and February, the dew-point within the concrete block cavity was higher than that of either the outside or inside ambient air. This indicates that moisture is present within the concrete block wall itself. It also indicates that this moisture did not move into the wall by water vapor pressure from either outdoors or indoors, because the pressure gradients slope toward both the indoor and outdoor face of the wall, away from the block cavity.

The water-spray test indicated that under appropriate conditions, such as high winds and concurrent rain, substantial liquid water can enter the wall. It was also shown that water leakage at windows can seep into the wall between the insulation board and the concrete block wall, and that water can penetrate the deteriorated paint film through capillary action at the many hairline cracks. The observations of water leakage into the wall at the footing indicates another mode for the moisture to infiltrate into the block wall. Although there are a few days during which moisture could also be transferred into the wall from the interior through vapor diffusion, it appears that the massive moisture accumulation within the wall is due to the four modes of liquid water entry outlined above. Furthermore, vapor diffusion from the interior would not have caused the water to form on the exterior side of the insulation as was found in April 1982 and May 1983.

During the occupant survey, it was found that almost two-thirds of the moisture problems were below or adjacent to windows. This suggests that window and sill leakage are a major factor causing the problems. Since moisture problems were also found on walls without windows, a second mode, either leakage through the wall or at the footing, may also be active in all or most of the problem areas under windows. Furthermore, the rain-screen installed to protect the window and wall at Stations 1 and 2 at Unit 2363 A did not allow the walls to dry out, although a reduction in moisture content was observed. Based on available data, it is not possible to state whether exterior wall leakage or capillary rise of moisture from the footing is the predominant cause of the moisture problem observed in walls not near a window. In some locations, such as the one where standing water was observed in the concrete block cavity, rainwater penetration through the wall must be the major cause, as the fact that the water could build up to an 18 inch head shows that leakage of the wall above grade was greater than the leakage of the same cavity below grade. In other areas, where water was observed to flow down the walls of the concrete block cavities, but did not collect or accumulate at the bottom of the cavity, the block cavity must have drained—conversely, water could also enter at this point. However, observations of standing water at or near building walls do not correlate well with reported moisture problems.

A major finding of the occupant survey was that of a total of 28 moisture problems, all but 2 were in bedrooms (problems relating to bath tubs and equipment rooms excluded). The windows in all rooms are of the same type and make, and the wall construction is uniform throughout the dwelling units. As is seen from the floor plans on Figures 12 and 13, the living and kitchen/dinette rooms are moderately sheltered from wind-driven rain. Also, the concrete rear patio in front of the living room, and the concrete court at the kitchen entrance, would reduce the possibility of water entering the wall from below grade. However, it is difficult to believe that the modest sheltering of the living/

kitchen/dining rooms could have prevented moisture problems in these rooms almost entirely.

The air infiltration tests showed that all houses in which measurements were made had very low infiltration rates. This was true based on both the tracer gas and pressurization tests. The tests also showed that the bedrooms have even lower air change rates than the house as a whole during periods when the heating or cooling fan was not operating, particularly with the bedroom doors closed. The occupant survey indicates that the bedrooms also appeared to be difficult to heat. The combination of very limited ventilation and low heat is a potential reason for the moisture problems to appear almost exclusively in the bedrooms. Both tend to inhibit the natural drying out of the gypsum board moistened by the water vapor driven towards the interior when the concrete block cavity is wet.

Table 16 shows for a few representative houses a comparative presentation of the various tests and investigations, and indicates the lack of a clear correlation between standing water, air infiltration rate, and incidence of moisture and/or mildew problems. It is because of this lack of correlation that the predominant causes for the moisture problems in any given location cannot be identified at this time.

7. RECOMMENDED REMEDIAL ACTIONS (CORRY FIELD)

7.1 Processes Causing Problems

The basic cause of moisture problems in the Corry houses is that moisture accumulates in the concrete block and tends to remain so year around in certain locations of the walls. Sunshine on the walls raises the temperature and dew-point in the cavities sufficiently to cause moisture condensation on the outer side of the insulation and on the gypsum board, and to wet the wooden furring strips.

Evidence was found during the field studies and tests that the concrete blocks were being wetted, the drying of the gypsum board prevented, or mold and mildew was formed through the actions and interactions of one or more of the following processes:

a) Rain or sprinkler-water leakage through the glazing gasket and window weatherstripping onto the sill and down into the furring space and over the wall surface.

b) Rain or sprinkler water entering through hairline cracks in the exterior surface.

c) Groundwater seepage into concrete wall cavities below grade above the foundation.

d) Inadequate wintertime ventilation.

e) Inadequate heat distribution to the bedrooms.

f) Lack of summertime moisture control in the bedrooms.

7.2 Recommended Constructional Measures

For each of the above causes and contributing factors, remedial measures are possible:

a) Repair or replace the windows. Replacement of the windows with double-glazed ones would also contribute to keeping the bedrooms warmer (see below). Whether windows should be replaced or repaired will need to be determined on the basis of a cost comparison which includes the potential need for future repairs and the energy savings possible due to double-glazing. Appendix 3 outlines the window repairs required.

b) 1. Seal all major cracks and coat exterior of house with a class of paint or coating having good elasticity and stable curing properties. An alternative would be the installation of exterior stucco. Appendix 4 gives outline specifications for the painting and coating. 2. Install automatic lawn sprinkler system designed to eliminate or reduce impingement of water on building walls.

c) 1. Clean and seal the joint between footing and concrete block wall, and parge and seal the wall below grade and to two inches above grade level. 2. Install gutters, downspouts, and splash blocks to prevent the deposition and accumulation of excessive rainwater near the house walls. Regrade the entire property to provide for better surface drainage away from the houses. 3. Install drain tiles and gravel around foundation if proper storm drainage can be provided.

d) Increase wintertime ventilation rate, particularly in bedrooms. This can be accomplished by installing small hygrostat-controlled exhaust fans or controlling the heater fan by a hygrostat located in the bedroom zone, or by providing a fresh air intake through the furnace, and by balancing the system so that required 0.5 ACH ventilation rate is provided in all rooms.

e) Increase heat input to the bedrooms. This can be accomplished by increasing insulation on heating ducts in attic, increasing the size of ducts supplying heat to the bedrooms, installing booster heaters in the ducts, or simply by proper balancing of the heating system.

f) Reduce indoor moisture in summer. This can be accomplished by using both temperature and humidity controls and a means for reheating the air when the system is being controlled by the humidistat. It may also be possible to modify the air conditioning equipment to increase its dehumidification capacity by reducing the air flow across the refrigeration coil. Finally, dehumidifiers could be installed in the bedrooms. Proper balance of the air conditioning system for summer conditions also will be needed.

Based on the observations and tests, it is concluded that the first two recommended measures—the repair or replacement of windows and the sealing of the exterior wall—are necessary to eliminate, or reduce to manageable proportions, the water leakage problems. To prevent the occurrence of the mildew problems, it is probable that additional measures to reduce the moisture in the bedrooms are needed. Whether and to what degree the other measures are needed cannot be ascertained based on the current data.

As a temporary measure, it is suggested that moisture damaged gypsum board in affected dwelling units be replaced by aluminum foil backed gypsum board. The aluminum backing (facing the thermal insulation) would tend to keep the gypsum board dry, although it would not eliminate the source of moisture in the concrete wall. It is also suggested that all kitchen and bathroom exhaust fans be checked and repaired if not in good working order. Additionally, it is recommended that all bathroom fans be wired directly into the light switch so that the fans operate whenever the rooms are occupied.

7.3 Pilot Program

The determination of which, if any, additional measures need to be implemented can best and most economically be accomplished through a pilot study in which a few houses are given various treatments. The results of the pilot program will lead to the determination of the most cost-effective methods to reduce or eliminate the problems. Except possibly for a drying-out period of houses which have experienced moisture problems in the past, all the test houses are to be occupied during the experiment. Although the exact number of houses involved may vary, and the specific actions installed may need to be changed, the pilot program should consist of the following elements. It is estimated that a total of 14 houses with a history of moisture or mildew problems would provide an adequate sample.

7.3.1 Selection of Houses. Some of the houses selected should have experienced wet gypsum board problems in exterior bedroom walls and some should have a history of mildew on exterior bedroom walls. Two houses should have experienced both moisture and mildew problems on exterior bedroom walls.

7.3.2 Control Group (Group 1). Two or more houses which had experienced both moisture and mildew problems will act as a control group.

7.3.3 Base Recommendation (Group 2). On a number of houses which had a history of moisture problems, repair or replace the windows as recommended in Appendix 3 by Architectural Testing. If the windows are replaced, install a double-glazed type. On all houses of this group, apply surface preparation to exterior of concrete block wall as recommended in Appendix 4. On two houses, apply acrylic latex paint (TT-P-19), as recommended in Appendix 4. On two or more houses, apply supplemental surface preparation and paint, and alternative surfacing systems as outlined in Appendix 4.

7.3.4 Seal Wall Below Grade (Group 3). On two or more houses with moisture problems, install the base recommendations outlined in 7.3.3 above. Excavate along the wall to below the top of the footing around the houses, except at concrete patios and walks, remove debris, roots, etc. from the joint between footing and wall, and clean the joint with sandblasting. Apply a water resisting parging to the joint and wall to provide a smooth surface, and apply a waterproof coating from the top of the footing to two inches above finish grade. Backfill such that positive drainage is provided.

7.3.5 Gutters and Downspouts (Group 4). On two or more houses with moisture problems, install the Base recommendations and install gutters, downspouts, and splash blocks, assuring that run-off from downspouts drains away from house.

7.3.6 Winter Ventilation and Summer Humidity Control by Reheat System (Group 5). On two or more of the houses with mildew problems, provide positive winter ventilation at a minimum rate of 0.5 ACH through the distribution system of the furnace and with a means to reduce it or cut it off during the summer. Check adequacy of duct insulation in the attic and repair or improve as indicated. Modify the air return circuit from the bedroom, if necessary, to balance the distribution of warm air with the bedroom doors closed. Equip the air conditioning units with both temperature and humidity controls and a means for reheat when the unit is being controlled by the humidistat. Rebalance the air distribution system for summer coooling, if necessary. Install meters to measure reheat energy use. Clean all mold and mildew from walls.

7.3.7 Winter Ventilation and Summer Humidity Control by Modifying Equipment to Increase its Dehumidification Capacity (Group 6). On two houses with mildew problems, install modification of heating system as in 7.3.6 above except for the installation of the humdistat, means for reheat, and meters to measure reheat. Modify (if possible) the air conditioning equipment by reducing the airflow rate across the refrigeration coil. This reduces the heat transfer between the air and the coil, and thereby reduces sensible cooling capacity, but increases the coil dehumidification capacity due to reduced coil surface temperature. Clean all mold and mildew from walls.

7.3.8 Drying-Out. If possible, remove gypsum board and insulation on walls where moisture problems have been observed. Air-condition and heat the houses to dry the walls out initially. Replace insulation and gypsum board after the dry-out period.

7.3.9 Provision for Measurements in Concrete Block Cavities. Provide access holes into the concrete cavity in or near locations where moisture problems (if any) have occurred, for measuring temperature and relative humidity in the concrete block cavity. The access holes should be fitted with removable plugs that are sealed except when readings are taken.

7.3.10 Hygrothermographs. Place hygrothermographs in the test houses. One each in a bedroom which had mildew or moisture problems, and one in the living room.

7.3.11 Paint Samples. From all houses which receive new exterior paint or coating, remove paint samples and analyse to determine the composition of the existing paint.

7.3.12 Monitoring. The experiment should run over at least a full year. During the year data should be taken for one or two days at monthly, bi-monthly, or quarterly intervals. After the one-year period, it may be decided to continue the monitoring, possibly at a reduced rate. If, after one year, there is significant evidence of moisture in the wall, the gypsum board and insulation will be removed for careful examination of the wall.

7.4 Maintenance and Operational Remedial Measures

While the discussion under 7.2 and 7.3 above stressed remedial measures related to constructional features which are needed to eliminate the problems, two types of remedial actions can be taken without major construction modifications. The first group consists of items related to upgraded maintenance. The second consists of actions that can be taken by the occupant.

7.4.1 Maintenance Measures. The most important—and least costly—of the maintenance measures is the careful sealing of the crack between the aluminum window frame and the window stool. This seal should be checked regularly. It can be accomplished easily by using the type of sealant used around bathtubs. Also at the window, exterior caulking and sealing the glazing joint can be done on a routine basis. These actions alone should significantly reduce the incidence of moisture problems. The efficacy of the seal at the window stool can be checked by placing water (for example, through an eye dropper or a syringe) along the joint and observing visually whether capillary action removes the water.

Increasing the frequency and quality of the exterior painting will also reduce the incidence of problems, but unless a paint such as recommended in Appendix 4 is used (with proper surface preparation), no estimate of the level of reduced problems can be given.

Proper balancing of the heating and cooling system will reduce the potential for both moisture and mildew problems and will, in addition, increase the comfort of the occupants and reduce their energy use. The inspection and increase of insulation of ducts in the attic could also be performed as a routine maintenance item.

In the surveys, it was found that in several homes, kitchen and bathroom fans did not operate 11/. Regular maintenance would reduce inoperative fans and increase the ventilation rate in affected housing units.

7.4.2 Operational Measures. The occupants of Corry Housing have an opportunity to reduce the potential for moisture and mildew problems in several ways.

On the exterior, the most significant contribution would be to ensure that lawn sprinkler water never touches building walls. Because wind can blow water from sprinklers some distance, this may require handwatering lawn and shrubs near the houses.

Within the houses, occupants should always use bathroom and kitchen exhaust fans when bathing, showering, and cooking. (All clothes dryers, of course, should be vented to the out-of-doors. Provision for this is provided at Corry Field.)

Whenever possible, doors to the bedrooms should be left open. This is particularly true during the night and when more than one person sleeps in a room. Occasional opening of windows (particularly early in the morning) would also reduce the potential for moisture problems in winter.

During the winter months at night, the heating fans should be operated in the manual mode; that is, the fans should run continuously, regardless of whether the heater supplies air. This would help in provided some much needed ventilation to the bedrooms.

8. LEXINGTON TERRACE

8.1 Description of Housing Units

The Lexington Terrace units are two-bedroom one-story semi-detached houses. They are built on a slab on grade, and exterior walls are brick masonry cavity walls, as shown on Figure 16. Their floor area is approximately 650 square feet. The roof is asphalt shingle hip with small triangular ventilation openings. Ceiling insulation is about 3 inches, without vapor retarder. The single bathrooms have one window, but no mechanical ventilation. The kitchen is equipped with an exhaust fan. A small utility/storage room has provision for installing washer and dryer. Most dryers at least appear to be vented through the roof. The houses have central gas-fired hot-air heat, but not central air conditioning. The houses are wired for window air conditioners, and about half of the houses have at least one window unit 10/. The houses were built in 1941.

8.2 General

During summer and fall, essentially the same tests were conducted at Lexington Terrace and Corry Field. Thereafter, the study concentrated on the Corry Field houses. This decision was reached because the Corry Houses are newer and represent a larger investment, and because potential solutions developed at Corry might also be applicable to the townhouses, and to Lexington Terrace.

The tests at Lexington Terrace consisted essentially of measuring the temperature and relative humidity of outdoor, indoor, and wall cavity air. The tests were conducted in vacant houses No. 333 and 375. Air infiltration tests and an occupant survey were also conducted.

As at Corry Field 2363 A, a rainshield was erected on two sides of the test house. Figure 17 shows the rainscreen in place. However, the screen was damaged early and probably was ineffective during the later part of the period in September when data were collected.

8.3 Temperature and Relative Humidity Measurements

A summary of the results of the measurements is given on Table 17. As can be seen, the relative humidities in the wall cavities were lower than those observed in the concrete block cavities of the Corry Field houses. However, similar to the results at Corry, the dew-point temperature within the brick wall cavity was also higher (with one exception) than the dew-point temperature of either the inside or outside air. But the dew-point temperature within the brick cavity wall was generally lower than either the outdoor or indoor dry-bulb temperature. Thus, while water vapor would move from the wall cavity toward both the outside and inside wall surfaces, under the conditions observed condensation is unlikely to occur in either the outer or inner portion of the cavity wall.

It is not known what caused the moisture to accumulate inside the wall cavity. Rain leakage may have contributed to that condition, or capillary rise from the ground. No subsequent or follow-up investigation was performed to identify the source of the moisture.

8.4 Visual Observations

Both houses No. 333 and 375 showed moisture-related damage. In the south wall of house No. 333 a damaged area was found at the left-hand lower corner of the window in the living room. The ceiling of the living room showed flaking paint. The bathroom had substantial paint failure and deterioration of the plaster walls.

In house 375, moisture damage was apparent only on the west walls of the two bedrooms. In one case, the damaged area was just below the ceiling. In the other, it was all along one jamb of a window from close to the ceiling to below the window sill. Inspection of the latter area on the building's exterior showed paint failure at the exact same spot, and serious paint flaking on the underside of the roof overhang above the damaged wall area. The wood window subframe also showed signs of rot on the exterior.

In general, the moisture damage observed in the two houses appears similar to that found by Elder 10/ in the survey of 25 houses (see below).

8.5 Air Infiltration Measurements

S-Cubed conducted air infiltration tests on houses No. 333 and 375. Air change rates of between 0.1 and 0.2 were measured. This corresponds to between 8.7 and 17.4 cfm. No tests were conducted on individual rooms. This is insufficient ventilation to remove the moisture generated within the houses as discussed in Appendix 1.

8.6 Occupant Survey

The survey was conducted by Elder and was reported directly to NCEL 10/. The results of that survey are summarized below:

Five (20 percent) of the 25 houses surveyed had significant moisture problems. Two of the five houses with moisture problems had problems in ceilings. It was reported that the problems became apparent after heavy rains. Most problems appeared to exist in the bedrooms, although one problem was reported on a kitchen wall. All the houses with moisture problems had at least one window air conditioner. The occupants reported using the kitchen exhaust fans always or often when cooking. Mildew problems were reported in seven of the 20 houses that had no significant moisture problems. The one difference between the houses with and without problems was that those occupants of the five houses with moisture problems who have spent a winter in their homes complained about difficulties in heating their houses sufficiently during the winter, while none of the occupants of the houses without problems mentioned this difficulty.

The results of the survey indicate the possibility of roof leaks. The houses had been reroofed about two years ago. It is not known whether the flashings at chimneys and vents were replaced at the same time.

8.7 Conclusions

The houses have several characteristics that can contribute to the moisture problems:

- o The uninsulated brick cavity walls have an R value only about 2.8. In winter, with high relative humidity, moisture could condense on the inside of the walls.

- The low infiltration rate aggravates the condition mentioned above in that moisture generated by occupants is not removed through ventilation.

- The bathrooms have no fans (although there are windows). Moisture from bathing will quickly dissipate throughout the dwelling unit if the door is open and the window closed.

- Presence of mildew without moisture problems indicated high relative humidity, low air infiltration rate in winter, and inadequate ventilation or dehumidification by air conditioning during the summer.

All of the above together or singly will contribute somewhat to the moisture problems. But it seems that rainwater leaks through windows and roofs may be a prime cause of the problem. Although the houses were reroofed only two years ago, major leaks could still exist at flashings. Also, some of the moisture problems appear of older origin, as no actual moisture was found in either of the two test houses (Nos. 333 and 375).

8.8 Remedial Measures

8.8.1 Constructional Measures

The following measures should be considered:

- Install exhaust fans in bathrooms wired into the light switch.

- Balance heating system.

- Check roofs and flashing and make all necessary repairs.

- Increase attic ventilation to the recommended 1/150 of attic area.

- Increase attic insulation, being careful to place insulation all the way out to the eaves.

- Repair or replace windows and wood window subframes.

- Apply a water resistant (but water-vapor permeable) paint on the exterior of the houses after proper surface preparation. See Appendix 4 for recommendations.

- Install gutters and downspouts, being careful that water drains well away from houses.

- Improve winter ventilation rate by supplying fresh air to the furnace air return intake.

- Seal joint between footing and wall and parge and waterproof wall below grade and up to two inches above finish grade.

- Install whole-house ventilation (through roof or window) to reduce need for air conditioning during summer months. This would reduce the potential for summer mildew problems, improve occupant comfort, and reduce energy use in houses equipped with air-conditioners. However, whole-house fans and air conditioners should not be used simultaneously.

Since the houses at Lexington Terrace are older and of lesser value than those at Corry, it is recommended that remedial measures be installed selectively only in those houses having current moisture problems. For example, where major problems occur in bathrooms, install the bathroom exhaust fan. Where the problem is flaking ceiling paint all over the house, increase attic ventilation. Where moisture problems occur below or at the jambs of windows, replace or repair the windows, and where roof leaks are strongly suspected (such as in house No. 375), repair roof and/or flashing. Such a house-by-house approach would be more cost-effective than the implementation of an ambitious retrofit program.

8.8.2 Maintenance and Operational Measures. Maintenance-type measures that can be implemented with little expense are primarily the upkeep of windows and, where necessary, the installation of weatherstripping to prevent major water leaks, and the monitoring of any suspected roof leaks. An upgrading of the quality of exterior wall paint (including surface preparation) and increase in frequency of repainting operations also should lead to a reduction in moisture problems.

The occupants can reduce moisture problems by increasing winter ventilation through the use of kitchen exhaust fans whenever cooking or when moisture condenses on windows and opening bathroom windows during or immediately after bathing and showering in winter, and by occasionally opening bedroom windows. Bedroom doors should be left open at night if possible. Occupants should not use lawn sprinklers so that sprinkler water touches building walls.

9. TOWNHOUSES

9.1 Description of Housing Units

Although the townhouses (on Base) were included in the original field visit, they were not investigated during this study except for two air-infiltration tests. Unlike Lexington Terrace and Corry Field, the townhouses are two-story rowhouses. They are larger than the Corry units. The wall sections are similar to Corry, except that the exterior has a stucco finish, as shown in Figure 18. One wall on the second floor is frame construction with wood sheathing. The houses were built about 1966. Unlike Corry and Lexington, the townhouses are in an area with large trees providing some shade and protection from driving rain.

9.2 Moisture Conditions

Although the townhouse development (on Base) was included in the April 1982 exploratory study, its houses were not investigated in depth during the conduct of the present study. The observations made in April 1982 were described in the report on the April 1982 field visit as follows: 1/

> Unoccupied unit 864 was inspected. In the kitchen, under a window on the east wall, an area about 2 feet by 3 feet had been freshly repaired, apparently because of peeling paint. In the laundry area where the clothes-dryer vent passes through the wall, the insulation was observed to be rock wool, with a polyethylene vapor retarder on the cold side. The exterior stucco showed hairline cracks but appeared to be generally in good repair. No moisture damage was observed in the ceiling or on the floor.

Although no survey data are available for the townhouses, discussions with NAS Housing Office and Public Works Engineering personnel indicate that moisture problems, while occurring, are less prevalent than at Corry.

9.3 Investigation and Conclusion

Air infiltration tests were conducted during the winter of 1982-1983 at a townhouse unit and will be reported by S-Cubed. It was found that while the blower-door tests at the townhouse indicated greater building tightness than that of the Corry Field house, the tracer gas tests indicated greater air changes. This is attributed to the fact that the townhouses are two-story, in which the "stack effect" causes greater air leakage under in-service conditions than is experienced in the one-story semi-detached Corry Field dwelling units.

Based on the limited available data, it appears that two factors contributed significantly to the reduced moisture problems in the townhouses when compared with the Corry Field units:

a) The stuccoed exterior of the concrete block walls provides a measure of protection against the infiltration of rain or sprinkler water into the concrete block, and

b) The increased air infiltration rate provides a means for drying out the moisture in the gypsum board interior finish.

From discussions with Base personnel, it appears that most moisture problems in the townhouses occur in the lower floor. The one house inspected in April 1982 apparently had a problem just repaired under a first-floor kitchen window. This would indicate that the primary mode for water to enter the wall is through the window, from the ground up, and from rainwater impinging on the wall.

9.4 Remedial Actions

Based on the above conclusions, recommended remedial actions include:

- Check, repair and/or replace windows.
- Parge and waterproof the joint between footing and concrete block wall, and the wall from the footing up to two inches above finished grade.
- Seal major cracks and repaint the stuccoed wall with a water resistant but water-vapor permeable paint, as outlined in Appendix 4.

Without further investigation, it is not possible to indicate which of the above actions would correct the most significant mode of wetting. However, when problems occur under windows, it would be logical to repair and recaulk the windows first (including the joints between the indoor window frame and the sill). Occupants should also be advised to always use the kitchen exhaust fans when cooking, and the bathroom exhausts when bathing. Bedroom doors should be left open at night if possible. Lawn sprinkler water was not observed to impinge on the walls of townhouses, but watering practices that might lead to this should be discouraged.

10. RECOMMENDATIONS FOR NEW HOUSING CONSTRUCTION

The main thrust of this project was the investigation of moisture problems in existing family housing at the naval air station in Pensacola, and the development of remedial measures to reduce or eliminate the problems. However, the study also pointed out directions for new construction for Pensacola and similar climate areas that would eliminate or drastically reduce similar problems in new construction in warm and humid climates.

10.1 General

The following concerns should be considered in the design and detailing of new housing in the Gulf Coast climate, regardless of construction type:

- Provide a water resistant but water-vapor permeable exterior finish. A stucco with an appropriate paint finish would give good protection in concrete masonry buildings. Metal siding or brick veneer would be acceptable in frame construction.

- Install good quality windows to prevent water leakage not only into the living space, but also into the wall construction.

- Provide for winter air change rates of no less than 0.5 ACH. It is important that the required air change rate be effective not only for the dwelling unit as a whole, but for all individual rooms.

- In buildings with a tight envelope, the required air change rate may best be achieved with mechanical ventilation through the furnace ventilation system. The installation of air-to-air heat exchangers, combined with mechanical ventilation, could also be considered.

- Wire bathroom exhaust fans into the lighting circuit so that the fans always operate when the bathroom is in use. Kitchen and bathroom exhaust fans should not be considered as alternatives for the mechanical ventilation suggested above.

- Assure that all rooms receive adequate heat—install adequate ducting and duct insulation where ducts run in the attic and maintain a balanced distribution system.

- For summer air conditioning equipment, follow design practices as outlined in "Air Conditioned Buildings in Humid Climates—Guidelines for Design, Operation, and Maintenance 7/. There also are innovative heat pumps being developed which use the waste heat to reduce the relative humidity of the air in the house.

- Consider installation of whole-house fans to reduce need for providing air conditioning. (However, air conditioning and whole house fans should not be operated simultaneously.)

- Install gutters, downspouts, and splash blocks (or connections to storm sewer) to reduce rain water deposit at base of exterior walls.

- Provide for adequate surface drainage.
- Install drain pipes and gravel around footings.
- Install an automatic lawn sprinkler system controlled by housing management staff. The system must be designed to prevent sprinkler water from impinging on house walls. (Such systems also would save water and energy.) Alternately, ground covers other than lawn should be considered.
- Provide attic ventilation area of at least 1/300 of attic floor area if a vapor retarder is installed in the ceiling, and at least 1/150 if no vapor retarder is installed.
- Install insulation in sidewalls and ceilings to provide U-values required by standard ASHRAE 90-80.

10.2 New Concrete Block Buildings

In the Gulf Coast climate, for new concrete-block housing units similar to those at Corry Field and the townhouses, several additional improvements are recommended:

- Fill all concrete block cavities below grade solid with mortar to prevent water from seeping into and accumulating within the block wall.
- Apply waterproof parging on exterior surfaces of all walls below grade and up to at least two inches above finished grade.
- Apply a stucco and/or coating on the exterior as recommended in Appendix 4.
- On the inside of concrete block walls, apply an effective vapor retardant coating directly to the interior face of the block wall. The coating must be continuous and not interrupted by furring strips. Surface preparation and mode of application may be critical and the manufacturer's application guidelines should be followed.
- An alternative high quality solution for concrete block walls would be the application of a closed-cell rigid plastic foam board on the exterior covered by a protective coating. This system has advantages resulting from placing the insulation on the building exterior and would provide a positive moisture proof shield. The system is described in a technical note by NCMA 12/. Figure 19 is reprinted from that TEK (see also Appendix 4). (Note that in this solution it is recommended that no vapor retarder be applied to the interior of the block wall.)

The first three of these recommendations are in agreement with the good practice recommendations in Architectural Graphic Standards 13/. (Although the recommendation is shown for a concrete block wall with wood joist floor), it also agrees with suggestions from the National Concrete Masonry Association 14/.

10.3 Other Construction Types

It was noted at Pensacola that none of the living units with frame construction (whether sheathed with wood or aluminum siding, or brick veneered) apparently exhibited the moisture problems so prevalent among the concrete block and brick constructions. In part this might be the result of greater water resistance of the exterior, in part of lesser capacity to store the water that does infiltrate, and in part it might be the result of the lower thermal mass of the framed wall construction. Although high thermal mass has been recommended for "composite climates" such practice applies more to climates having distinctive warm and humid, and cold and dry seasons. Even then, Koenigsberger 15/ recommends that the mass be concentrated in the floor and on the interior of the space, e.g., in interior partitions, combined with a well insulated but low-thermal-mass exterior wall.

Frame wall buildings might reduce serious moisture problems. However, air conditioning systems that effectively remove the excess moisture from the air in summer would still be important to eliminate the potential for mildew problems in such buildings. Similarly, adequate ventilation (no less than 0.5 ACH) and heat in winter, and water resistant exterior finishes would still be necessary to eliminate moisture problems throughout the year in the Pensacola climate.

11. REFERENCES

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Table 1. Dry-bulb and Dew-point Temperatures in the Concrete Block Cavities, Indoors & Outdoors for Corry Unit 2363 A Under Summer Conditions

		Station 1	Station 2		Station 3		
Time	Indoor	Bottom	Top	Bottom	Top	Bottom	Outdoor
Dry-bulb Temperature, F, September 17, 1982							
4:30 AM	78	79	79	80	80	79	76
12:30 PM	81	96	91	89	86	88	91
4:45 PM	77	86	95	93	91	88	89
10:30 PM	79	83	85	85	84	83	78
Dew-point Temperature, F, September 17, 1982							
4:30 AM	65	79	74	76	80	76.5	74
12:30 PM	62	92.5	81.5	81	86	86	77.5
4:45 PM	58.5	86	95	93	89	88	77
10:30 PM	56.5	83	81.5	81	84	81	76.5
Dry-bulb Temperature, F, September 18, 1982							
6:00 AM	78	77	78	78	78	78	75
9:30 AM	76	81	79	79	79	79	80
6:30 PM	79	88	84	84	82	81	80
10:30 PM	77	80	81	81	81	80	79
Dew-point Temperature, F, September 18, 1982							
6:00 AM	59.5	77	72	72	75.5	75.5	71.5
9:30 AM	56.5	81	74	73.5	78.5	79	76.5
6:30 PM	57	88	81	80.5	82	81	77
10:30 PM	63.5	80	76	76	80.8	77	77
Dry-bulb Temperature, F, September 19, 1982							
9:30 AM	78	81	79	79	79	78	79
1:30 PM	79	91	78	77	88	80	84
Dew-point Temperature, F, September 19, 1982							
9:30 AM	70.5	81	73	73	78	76.5	76.5
1:30 PM	65	81	75.5	74	86	80	80.5

Table 2. Total Monthly Rainfall, June 1982 to February 1983 at Pensacola, Florida, Provided by J. Williams, NSF Weather Station

Month		Total Rainfall
1982	June	6.49
	July	9.84
	August	4.73
	September	1.81
	October	2.71
	November	2.95
	December	6.99
1983	January	4.97
	February	13.11

Table 3. Summary Weather Data for Pensacola, Florida*

	Avg. of Daily Max.** Temp F	Avg. of Daily Min.** Temp F	Monthly Average** Temp F	Monthly Average** Dewpoint F	Monthly Avg. Relative Humidity %	Monthly Average Precipitation Inches***
January	65	48	55	45	80	4.2
February	65	46	57	46	75	4.6
March	70	52	65	50	75	4.9
April	75	60	68	60	75	3.8
May	84	65	75	65	75	3.7
June	91	71	82	71	75	4.7
July	91	75	82	75	80	5.4
August	91	75	83	73	80	5.4
September	85	71	80	70	80	6.7
October	80	61	70	60	75	4.0
November	70	50	60	48	75	3.2
December	65	45	55	45	80	4.1

*Extracted from NOAA Weather Atlas.
**Interpolated from 5-degree or 5-percent isotherms.
***From Pensacola NAS Weather Data, average for period of record from January 1952 to December 1982

Table 4. Dry-bulb and Dew-point Temperatures in the Concrete Block Cavities, Indoors & Outdoors, for Corry Unit 2363 A Under Winter Conditions

	Date and Time of Day														
	Jan. 17 '83 11:30 am–Noon			Jan. 18 '83 9:15–9:30am			Jan. 19 '83 1:00–2:00pm			Jan. 20 '83 10:00–10:30am			Jan. 20 '83 2:00–3:00am		
	DB	RH	DP	DB	RH	DP	DB	RH	DP	DB	RH	DP	DB	RH	DP
Station															
Indoors	70	31	29	68	38	41.5	69	33	39	69	40	44	65	52	47
Outdoors	57	35	22	42	46	24	44	66	34	48	89	46	48	86	44
1	72	100	72	56	88	53	52	92	50	51	90	48	54	92	52
1A	-	-	-	-	-	-	55	93	53	53	91	50	54	91	51.5
2	56	65	45	50	56	35	53	63	41	54	62	41.5	52	69	42
3	54	92	52	46	91	44	50	89	47	51	89	48	51	91	49
4	53	95	51.5	46	92	44	51	88	47	51	89	47	51	88	48
Weather	Sunny			Sunny			Light Rain			Heavy Rain			Light Rain		

Table 5. Dry-bulb, Relative Humidity and Dew-point Temperatures in the Concrete Block Cavity, Indoors and Outdoors, for Corry Unit 2363 A on February 25, 1983

Time	7:00–8:00 am			10:30–11:10am			1:50–2:25pm			4:05–4:30pm			8:15–9:00pm		
Temperature	DB	RH	DP	DB	RH	DP	DB	RH	DP	DB	RH	DP	DB	RH	DP
Station															
Indoors	70	65	57.5	71	76	63	74	62	60	73	67	61.5	69	64	56.5
Outdoors	55	85	51	57	60	43	63	41	39	60	39	35	52	50	34
1	61	93	59	77	102	77	85	104	85	81	99	81	67	103	67
1A	61	94	59.5	77	102	77	87	105	87	81	102	81	67	101	67
2	60	73	51.5	65	71	55	73	76	65	80	83	74.5	69	82	63.5
3	59	94	57	60	97	59	66	91	63	64	95	62.5	60	94	58.5
3C	59	97	58	61	95	59.5	63	96	62	65	95	63.5	59	100	59
3D	58	98	57.5	60	97	59	62	97	61.5	66	93	64	58	101	58
4	59	91	56	63	90	60	70	104	70	79	103	79	59	96	58
Weather	Partly Cloudy Strong Wind			Sunny			Sunny			Sunny			Clear		

Table 6. Dry-bulb, Relative Humidity, and Dew-point Temperatures in Concrete Block Cavity, Indoors and Outdoors, for Corry Unit 2363 A on May 16, 1983

MAY 16, 1983
10:15- TO 10:50 AM

STATION	DB	RH	DP
INDOORS	76	82	70
OUTDOORS	74	80	67.5
1	79	95	77.5
1A	79	95	77.5
2	77	71	67
3	76	96	75
3C	75	97	74
3D	75	99	75
4	75	94	73.5

Table 7. Average Dry-bulb, Relative Humidity, and Dew-point Temperatures Indoors, Within Concrete Block Cavities, and Outdoors During the Six Observation Periods From September to May

	SEPTEMBER 16-20			SEPTEMBER 21-24			NOVEMBER 16-19			JANUARY 17-21			FEBRUARY 18-23			MAY 16		
	DB	RH	DP	DB	RH	DP	DB	RH	DP	DB	RH	DP	DB	RH	DP	DB	RH	DP
INDOOR	79	56	62	67	49	47	72	60	58	69	39	43	70	63	57	76	84	71
CAVITY	84	90	82	74	92	72	71	85	66	55	86	51	65	94	64	77	92	75
OUTDOOR	81	84	76	69	62	56	72	82	67	48	61	37	59	66	48	74	86	70

Table 8. Moisture Content of Wall Materials

(By Pensacola Testing Laboratory, Inc. Except for January Tests Conducted by H. R. Trechsel Associates)

MOISTURE CONTENT OF WALL MATERIALS
(PERCENT BY WEIGHT)

STATION AND LOCATION	MATERIAL	AUGUST	SEPTEMBER	NOVEMBER	JANUARY
1 INSIDE	CONCRETE BLOCK	3.1	NA	2.5	NA
1 OUTSIDE	CONCRETE BLOCK		6.4*	4.7	NA
1 INTERIOR	GYPSUM BOARD	15.3	23.3**	17.5	NA
2 INTERIOR	GYPSUM BOARD		NA	13.3	NA
3 OUTSIDE HIGH	CONCRETE BLOCK		NA	6.8	NA
3 WEB HIGH	CONCRETE BLOCK		NA	10.3	8.5
3 INSIDE HIGH	CONCRETE BLOCK		NA	9.1	2.3
3 INTERIOR HIGH	GYPSUM BOARD		NA	2.0	12.8
3 INTERIOR LOW	GYPSUM BOARD		NA	0.5	NA
3 INSIDE LOW	CONCRETE BLOCK		NA	8.6	NA
4 INTERIOR	GYPSUM BOARD	13.6	13.8	12.2	

* AVERAGE OF TWO READINGS AT 3.1 AND 9.7

** AVERAGE OF THREE READINGS OF 21.4, 35.2, AND 13.25 PERCENT.

NOTE:

SAMPLE LOCATIONS ARE NEAR, NOT DIRECTLY AT THE MEASUREMENT STATIONS. SAMPLES COLLECTED DURING SUCCESSIVE MONTHS ARE NEAR, BUT NOT FROM THE EXACT SAME LOCATION.

Table 9. Summary of Measured Air Change Rates in Corry Field No. 2363 A and 2381 B in November.

(By S-Cubed)

House	Occupied/Unoccupied	Remarks	Air Change Rate
2363 A	Unoccupied	*	0.2
2363 A	Unoccupied	Bedrooms only** Doors open	0.1 Average
2363 A	Unoccupied	Bedrooms only** Doors closed	-0-
2381 B	Occupied	***	0.3

* HVAC fan operating

** Fan shut off

*** Container method test

Wind speed for all tests below 5 mph

Table 10. Air Change Rates Measured by Container Method in Selected Occupied Houses at Corry Field.

(By S-Cubed)

2303 B	0.53	2317 B	0.16	2368 A	0.25
2304 A	0.26	2319 B	0.26	2372 A	0.27
2305 A	0.19	2322 B	0.17	2373 B	0.18
2305 B	0.49	2331 A	0.22	2381 B	0.21
2308 B	0.26	2338 A	0.25	2381 B	0.21
2310 A	0.34	2339 B	0.36	2386 A	0.22
2311 A	0.49	2351 B	0.25	2397 A	0.29
2313 A	0.21	2352 A	0.40	2398 A	0.28
2316 B	0.23				

Table 11. Results of Ground Drainage Tests (November)

Short Test (1/2 Hour Wetting)		Long Test (12 Hour Wetting)	
Time (After Water Shut-off)	Drop In Water Level	Time (After Water Shut-off)	Drop in Water Level
Minutes	Inches	Minutes	Inches
0	Saturation, Standing Water	0	Saturation, Standing Water
5	1	5	-0-
10	1 1/2	10	-0-
15	2	15	-0-
25	6		
40	8 1/2 (Below top of footing)	30	1 1/4
6 hr. 40 min.	15	1 hr. 45 min.	10 (Below top of footing)

Table 12. Summary Data on Sprinkler Test (All on Station 3)

	Before Sprinkling			During Sprinkling		
	DB	RH	DP	DB	RH	DP
High	82	96	-	73	100	-
Average	72	91	69.5	66.2	94.3	64.5
Low	64	88	-	61	85	-

Table 13. Summary Data on Ground Wetting Test (Station 4)

	Before Wetting			During Wetting		
	DB	RH	DP	DB	RH	DP
High	86	92	-	89	100	-
Average	73.4	89.5	69.5	74.3	91.6	72
Low	63	85	-	61	84	-

Table 14. Air and Surface Temperatures in and Near Exterior Walls

	November 19, 1983		May 16, 1983	
	Station 1	Station 3	Station 1	Station 3
	(10:00 am)		(11:00 am)	
Ambient Outside Temperature	77 F	77 F	76 F	76 F
Outside Block (a)* Temperature	77	77	84	76
Outside Cavity (b) Temperature	76	77	81	76
Inside Cavity (c) Temperature	76	77	78	76
Interior Block (d) Temperature	78	77	77	77
Surface Gypsum (e) Temperature	77	77	75	75
Ambient Inside Temperature	76	77	74	74
Relative Humidity in Cavity	94%	95.7%	95%	96%
	Sun on Wall		Sun on Wall	

* See Figure 9 for location

Table 15. Water-Vapor Permeance of Interior Gypsum Board.

(By Pioneer Laboratory, Inc., Pensacola, Florida)

		Perm	ng/Pa S.m^2
Control	1.	76.40	4387
(Unpainted)	2.	58.30	3397
	$\bar{X}$	67.35	3892
Sample #2	1.	37.43	2150
(Painted)	2.	46.90	2695
	$\bar{X}$	42.16	2422
Sample #4	1.	40.35	2318
(Painted)	2.	35.50	2039
	$\bar{X}$	38.00	2183

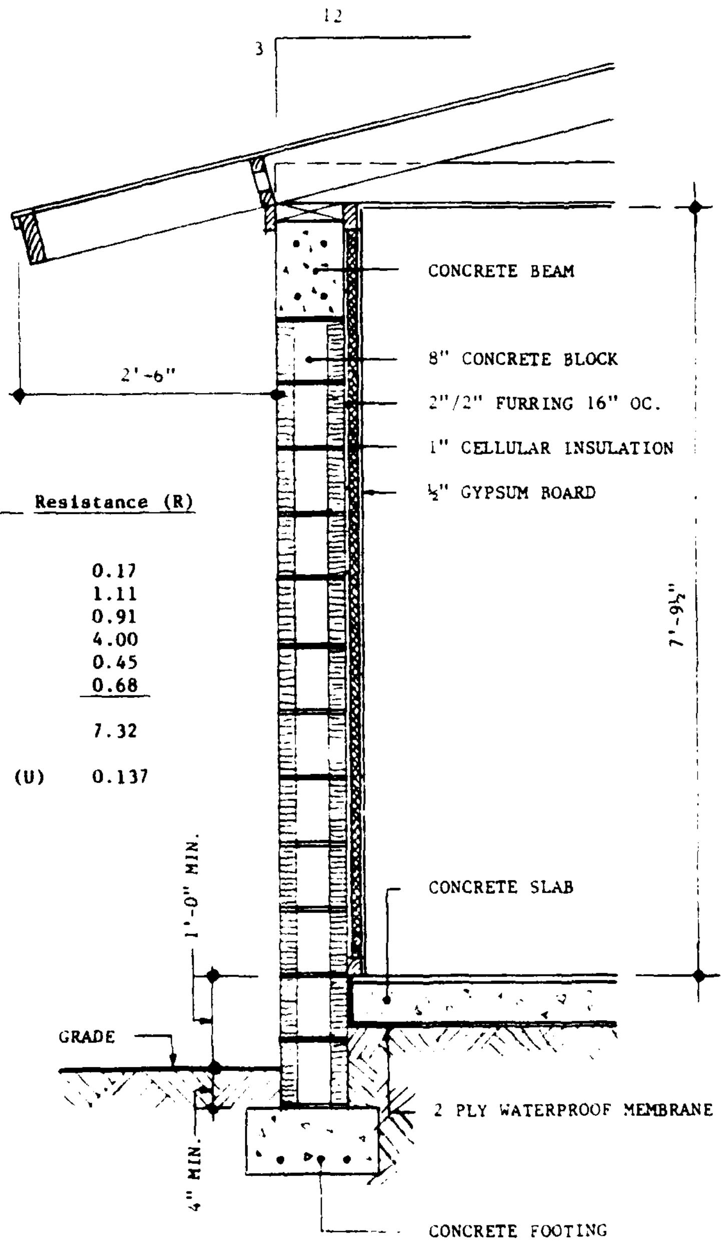
Table 16. **Summary of Occupant Survey, Infiltration Rate, and Observation of Standing Water on Ground**

House	Moisture Problem	Mildew Problem	Infiltration Rate	Standing Water
2303 B	No	No	0.53	NA
2304 A	No	Yes	0.26	NA
2305 A	Yes	No	0.19	Yes
2305 B	Yes	Yes	0.49	Some
2308 B	No	Yes	0.26	NA
2310 A	Yes	No	0.34	Yes
2311 A	Yes	No	0.49	Yes
2311 B	No	No	NA	Some
2313 A	No	No	0.21	NA
2316 B	No	Yes	0.23	NA
2317 B	Yes	No	0.16	Yes
2319 A	Yes	No	NA	Yes
2319 B	Yes	No	0.26	NA
2322 B	No	No	0.17	NA
2331 A	No	Yes	0.22	NA
2338 A	Yes	Yes	0.25	NA
2339 B	No	Yes	0.36	NA
2351 B	No	No	0.25	Yes
2352 A	Yes	Yes	0.40	Some
2352 B	No	No	NA	Yes
2368 A	No	Yes	0.25	NA
2372 A	Yes	No	0.27	NA
2373 B	Yes	No	0.18	NA
2380 B	No	No	NA	Yes
2381 A	No	Yes	0.38	Some
2381 B	Yes	No	0.21	Some
2386 A	No	Yes	0.22	NA
2397 A	No	Yes	0.29	NA
2398 A	Yes	No	0.28	Yes
2398 B	Yes	No	NA	Yes

NA = Not Available

Table 17. Summary of September Data on Dry-bulb Temperature, Relative Humidity, and Dew-point Temperature at Lexington Terrace.

	Warm Period September 16-19						Cool Period September 20-23					
	DB	RH	DP	DB	RH	DP	DB	RH	DP	DB	RH	DP
No. 333 (Wall Cavity)	West Wall			South Wall			West Wall			South Wall		
High	91	94	-	89	94	-	79	72	-	78	82	-
Average	85	81.2	79	85.9	85.6	81	72.2	67.2	61	74	76.4	66.5
Low	78	73	-	83	79	-	64	59	-	67	64	-
No. 375 (Wall Cavity)							West Wall			North Wall		
High			Not Collected				80	91	-	80	68	-
Average			Not Collected				73.8	70.5	64	73.8	59	58.5
Low			Not Collected				68	59	-	67	51	-
Outdoor (Both Houses)												
High	89	86	-				83	70	-			
Average	83	63	69				74.3	54.3	57			
Low	78	50	-				62	39	-			
Indoor (Both Houses)												
High	92	79	-				84	70	-			
Average	85.6	70.4	75				78.5	58.5	63			
Low	80	64	-				73	47	-			



Construction	Resistance (R)
Outside surface (15 mph)	0.17
Concrete block	1.11
Air space, 5/8"	0.91
Board insul.	4.00
Gypsum board	0.45
Inside surface	0.68
Total resistance (R)	7.32
Thermal transmittance (U)	0.137

Figure 1. Wall Section Corry Field

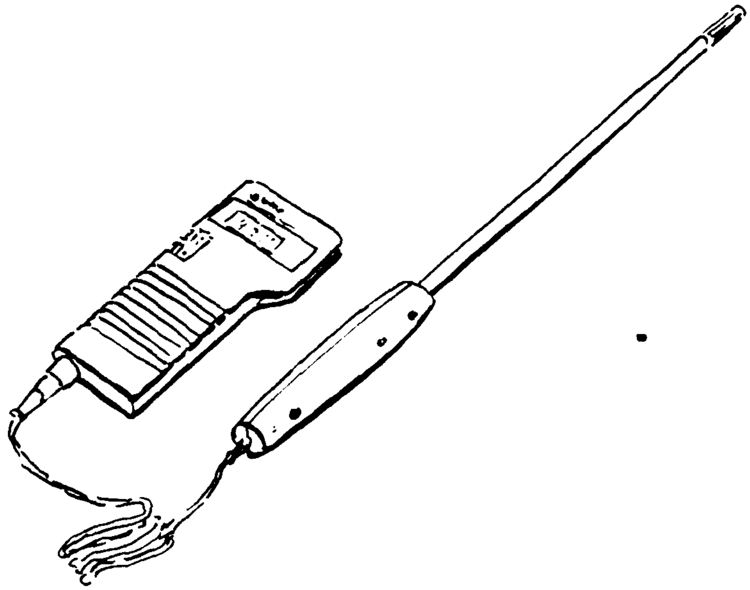


Figure 2. Temperature and Relative Humidity Measurement Instruments

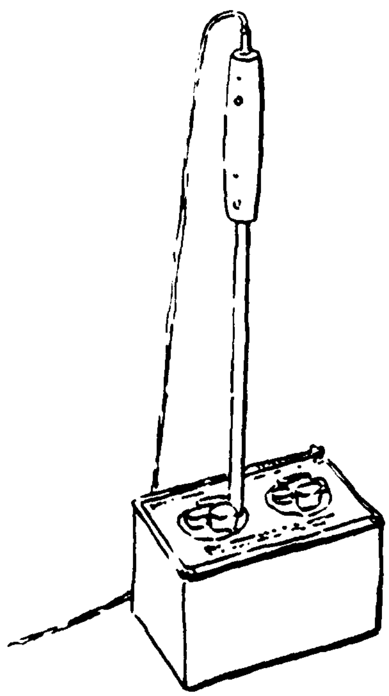


Figure 3. Temperature and Humidity Probe Inserted into Calibrator

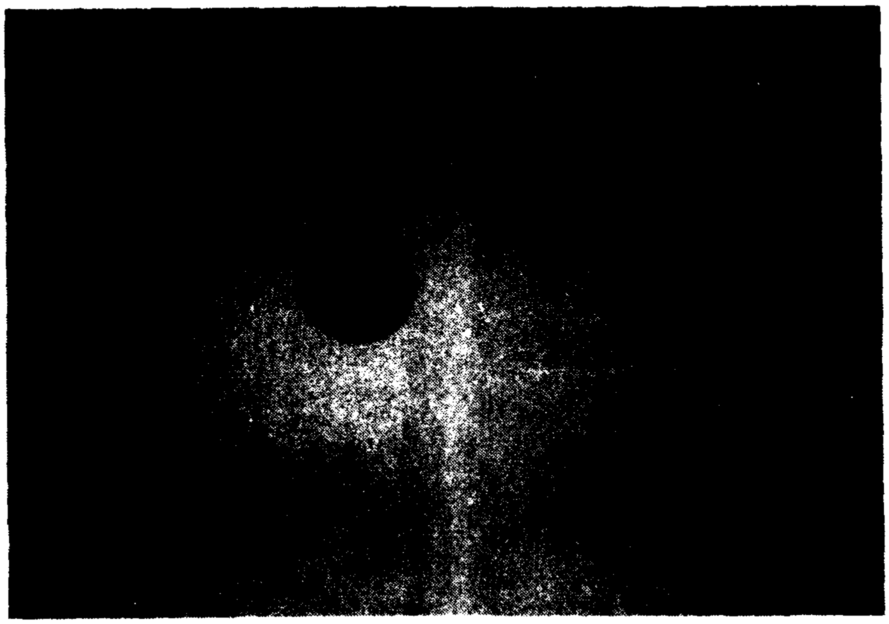


Figure 4. Prepared Hole for Temperature and Relative Humidity Probe

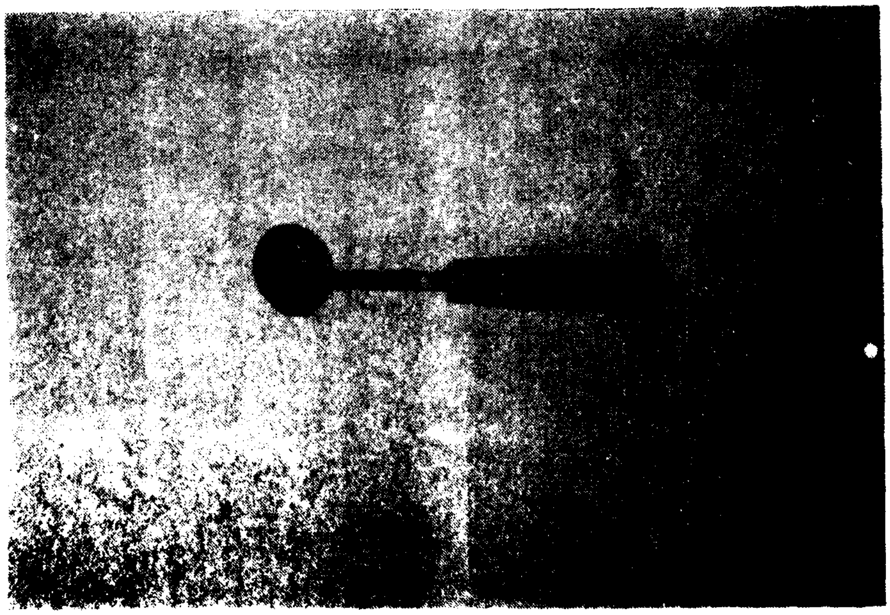


Figure 5. Probe Inserted into Hole

Figure 6. Rainshield Installed on Corry Field Unit No. 2363 A

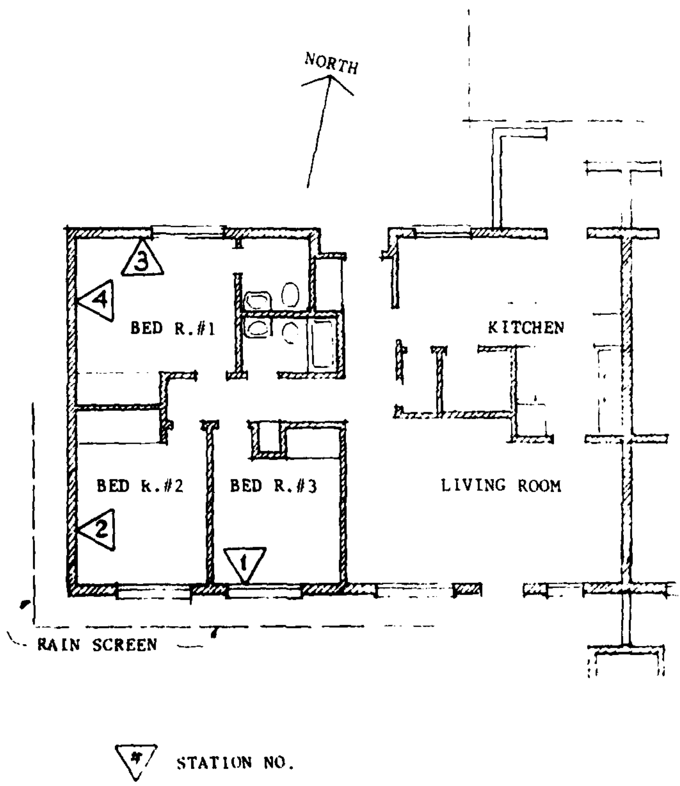


Figure 7. Stations In Corry Field House - Floor Plan

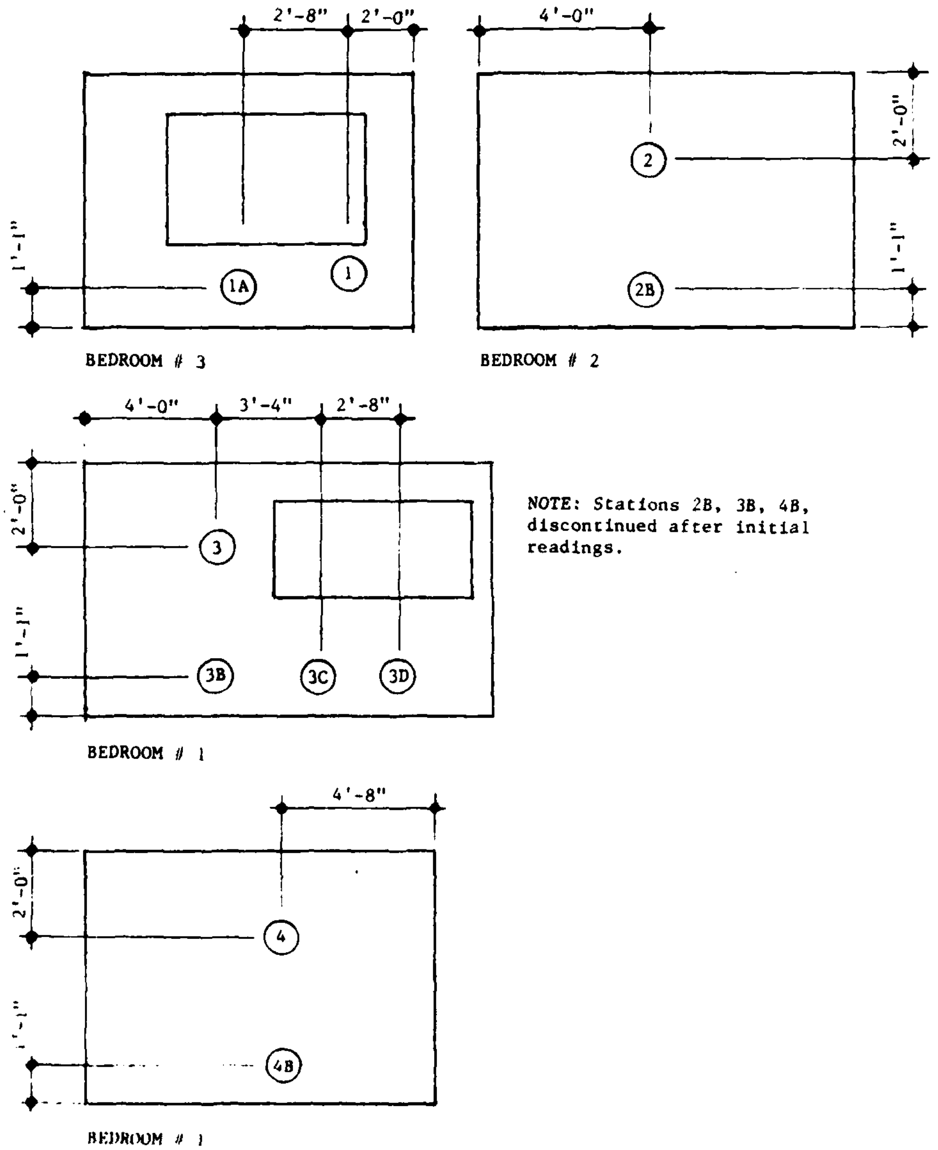


Figure 8. Stations in Corry Test House - Wall Elevations

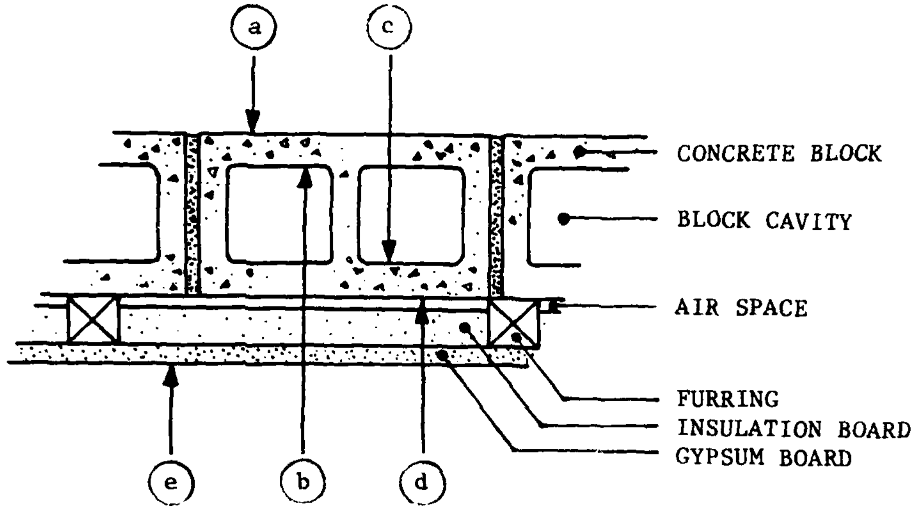


Figure 9. Surface Temperature Probe Locations

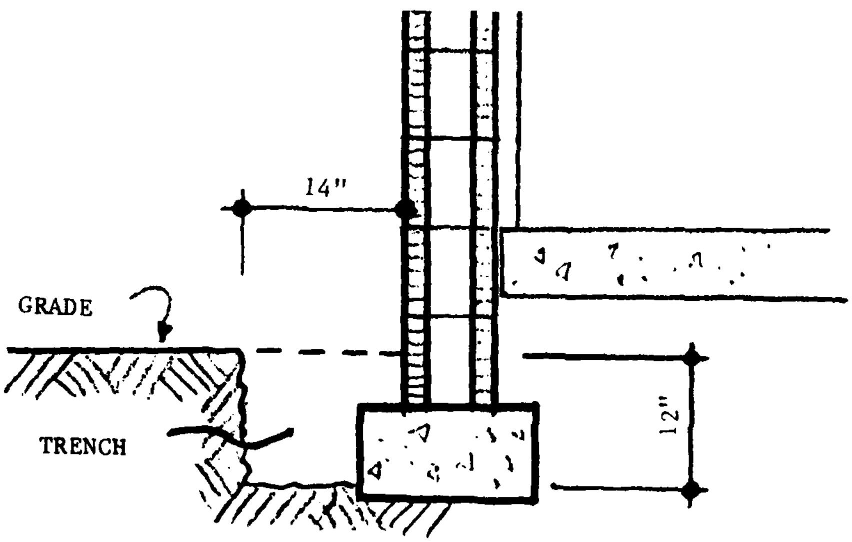


Figure 10. Trench at Footing

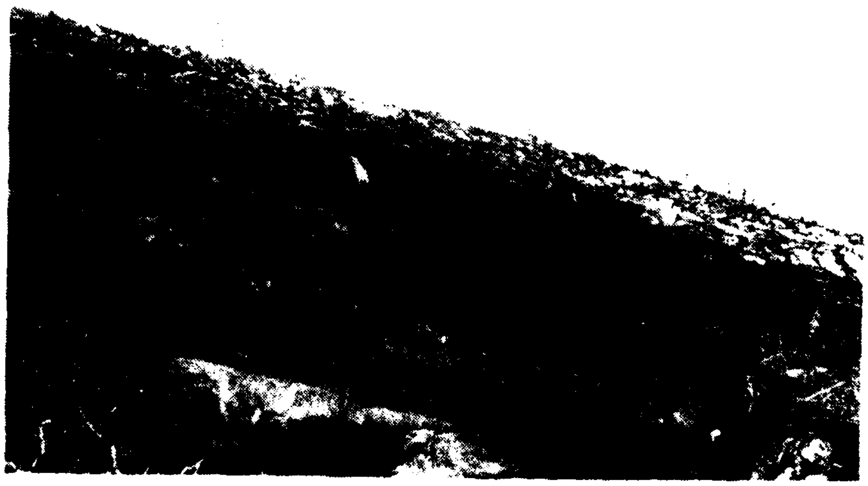


Figure 11. Trench After Waterproofing is Applied

Photograph taken shortly after heavy rain. Grass clippings and debris show maximum level of water approximately 4" above original grade. Waterproofing applied up to 2" above grade.

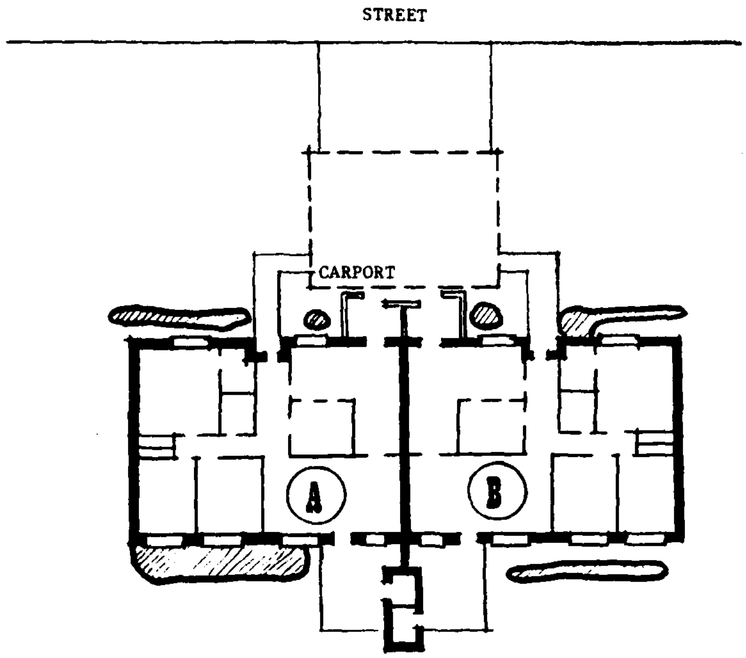


Figure 12. Diagram of Standing Water Near Houses 2310 A and B, Classified as "Heavy" Amount Standing Water

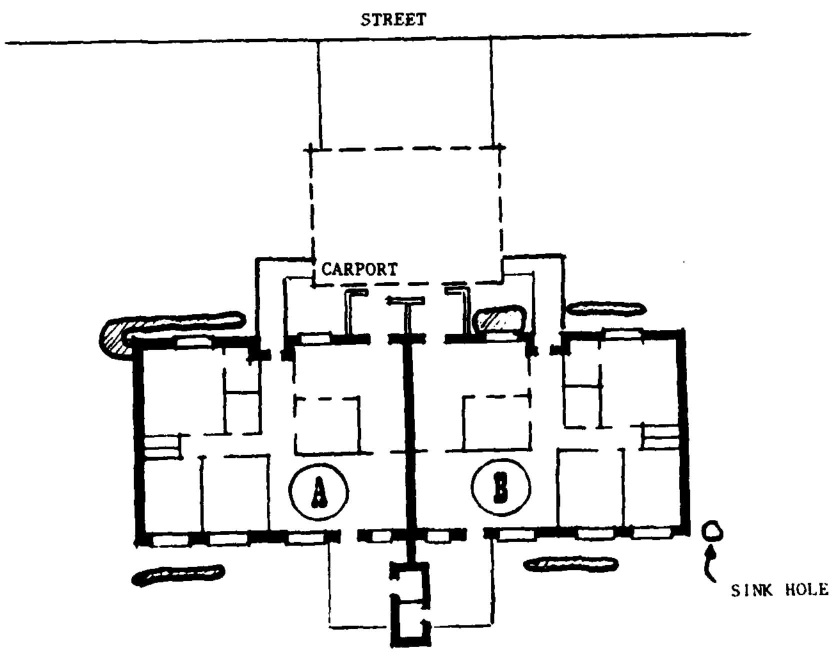


Figure 13. Diagram of Standing Water Near Houses 2381 A and B, Classified as "Moderate" Amount Standing Water

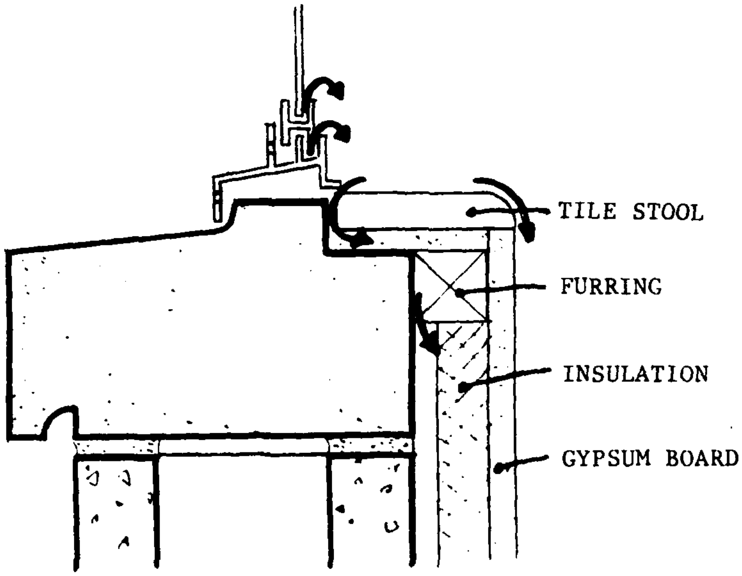


Figure 14. Leakage Paths of Water at Window Sill

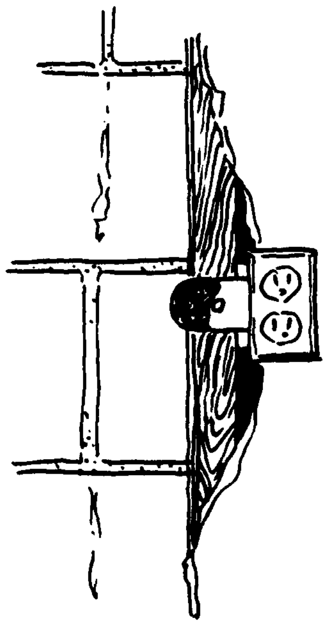
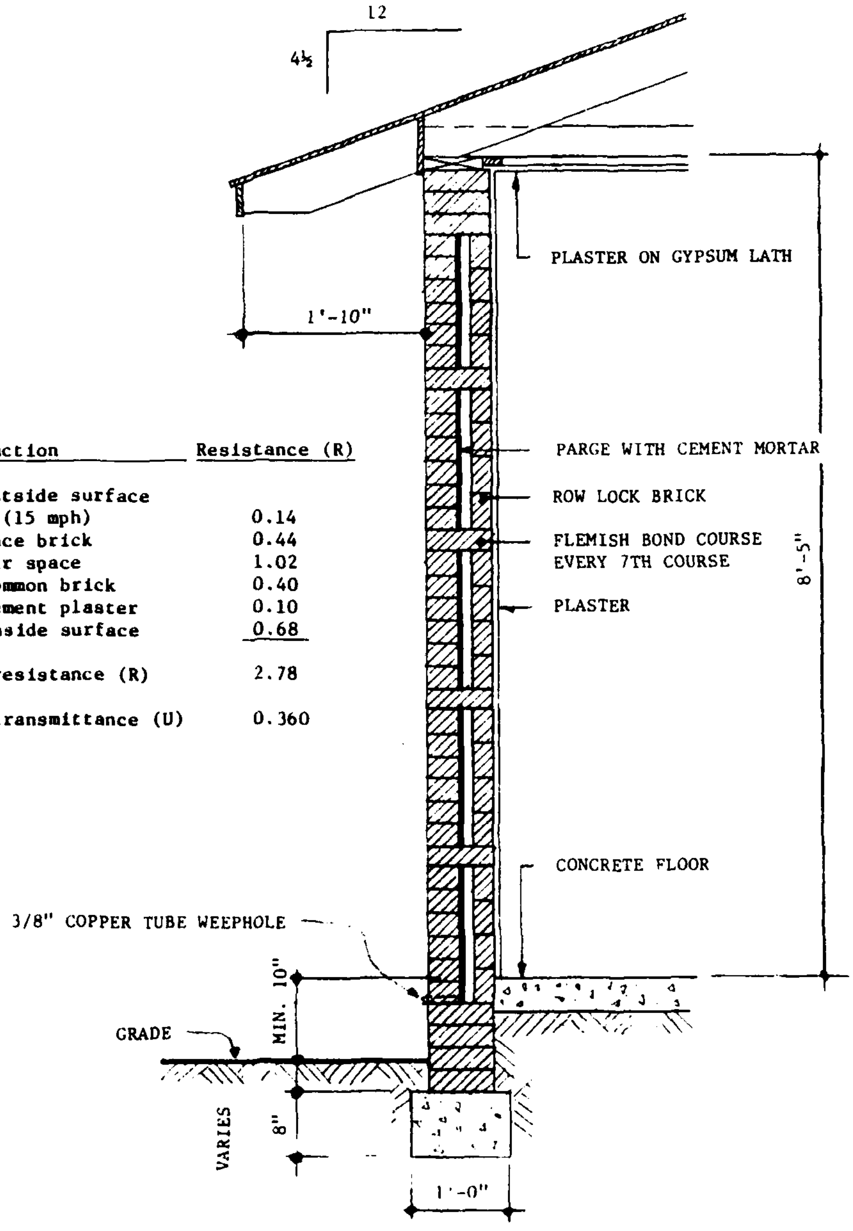


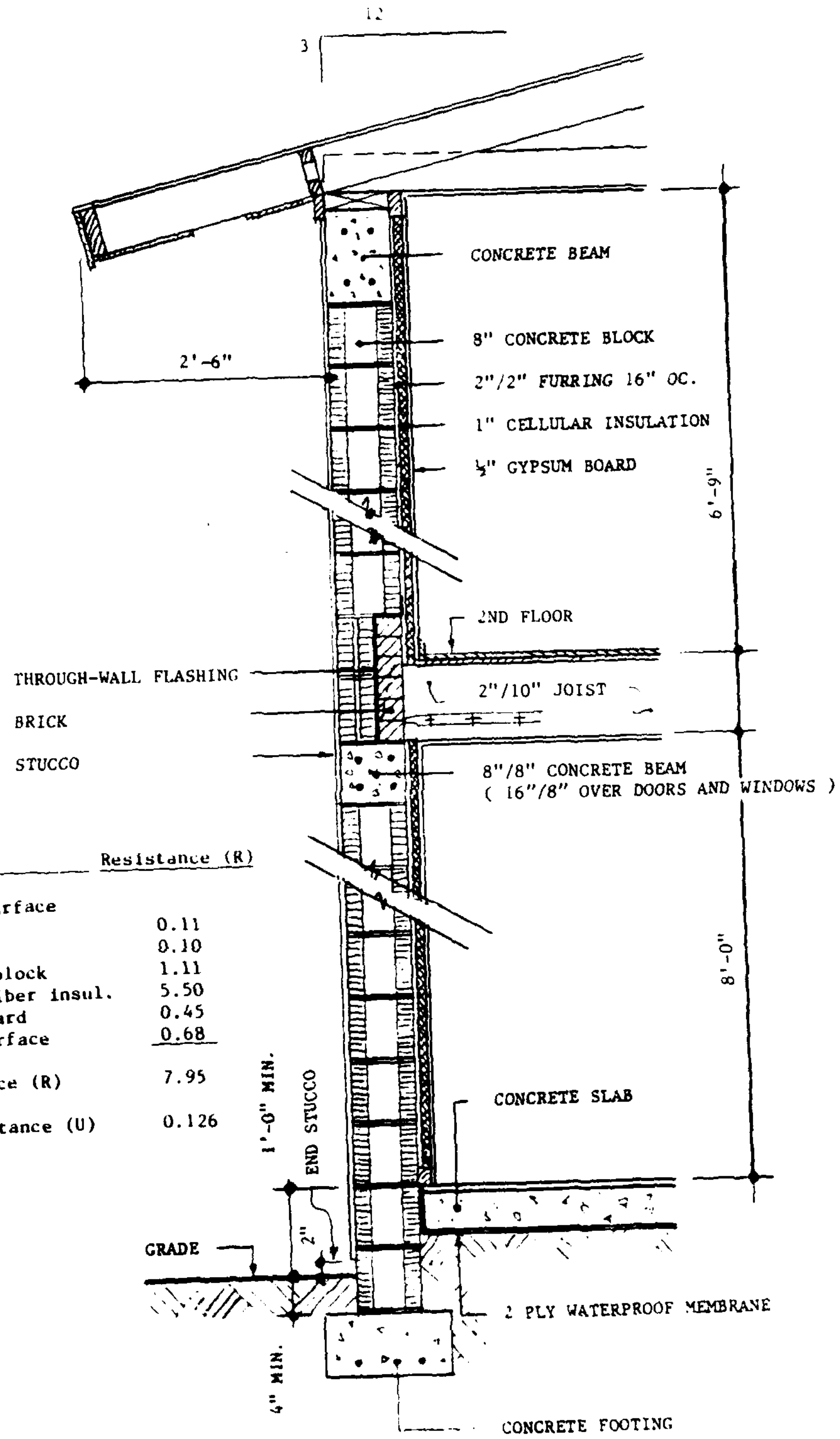
Figure 15. Rusted Mounting Bracket of Electric Outlet Near Leakage Site



Construction	Resistance (R)
Outside surface (15 mph)	0.14
Face brick	0.44
Air space	1.02
Common brick	0.40
Cement plaster	0.10
Inside surface	0.68
Total resistance (R)	2.78
Total transmittance (U)	0.360

Figure 16. Wall Section Lexington Terrace

Figure 17. Lexington Terrace Unit 333 With Rainscreen in Place



Construction	Resistance (R)
Outside surface (15 mph)	0.11
Stucco	0.10
Concrete block	1.11
Mineral fiber insul.	5.50
Gypsum board	0.45
Inside surface	0.68
Total resistance (R)	7.95
Total transmittance (U)	0.126

Figure 18. Wall Section Townhouses

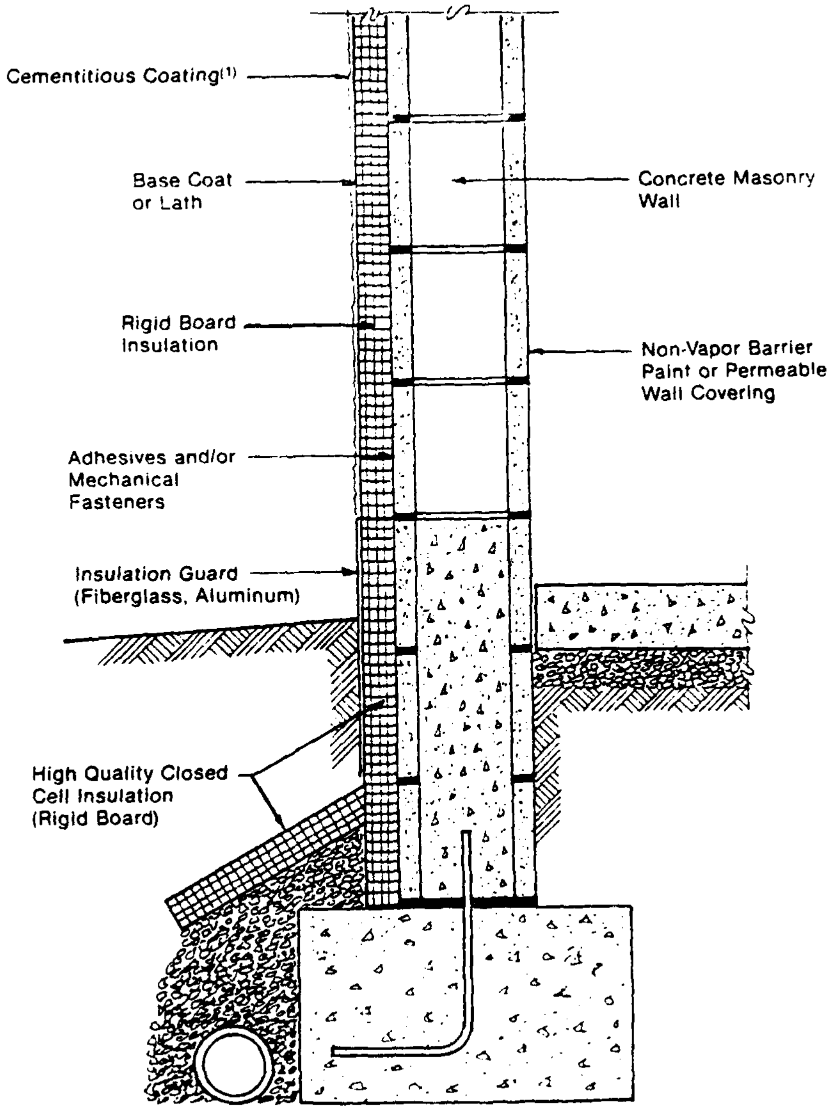


Figure 19. Concrete Block Wall with Exterior Insulation

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APPENDIX 1

CALCULATIONS OF WINTER VENTILATION REQUIREMENTS

Published data indicate that a typical family of four will release about 18 to 25 lb of water per day into their residential environment in the form of water vapor 1-3/. Today, with less cooking, less floor scrubbing, fewer daily hours of house occupancies, and with clothes dryers vented to the out-of-doors, 16 lb of water per day (equivalent to 0.67 lb/hr) may be more appropriate. This is the amount of vapor release assumed for the calculations below. This moisture comes from respiration, perspiration, cooking, dishwashing, personal hygiene, plants, etc. This level of moisture release does not include evaporation of moisture from wet walls or from floors accidentally wetted.

The Corry housing units have about 1200 square feet of floor area and about 9600 cubic feet of volume. At 75°F DB and 50 percent R.H. this volume of air corresponds to a weight of about 700 lb of dry air.

During the colder months of the winter, the water vapor produced indoors can be dissipated by ventilation with outdoor air. For example:

Table 2 shows that the average outdoor conditions for March in Pensacola are DB 65°F, R.H. 75 percent, and DP 50°F. The moisture content of the outdoor air at this condition is 0.0076 lb of water vapor per pound of dry air. If then a ventilation rate of 1 air change per hour were provided for dissipation of the indoor moisture, the 700 lb of dry air equivalent would have to absorb 0.67 lb/hr of water vapor generated indoors. This would represent $\frac{0.67}{700}$ = 0.00096 lb of water vapor/lb of dry air increase in the moisture content of the ventilating air. That is, the exhaust air would have a moisture content of 0.0076 + 0.00096 = 0.00856 lb of water vapor per pound of dry air. This corresponds to a dew point of 53°F for the exhaust air. If the indoor air temperature was being maintained at 75°F, its relative humidity would be about 46 percent for this typical moisture release rate in the house. Correspondingly, if the indoor temperature were maintained at 70°F, the relative humidity would be about 55 percent.

However, the measured infiltration rate in Corry unit 2363A on a whole-house basis was only 0.2 air changes per hour with the furnace fan operating (see Table 11). Using the same analytic process as above, the 0.67 lb/hr of water vapor would have to be dissipated by only 140 lb/hr of air corresponding to an increase of 0.0048 lb of water vapor/lb of dry air in the exhaust air, or a total moisture content of 0.0124 lb./lb., which indicates a dew-point temperature for the exhaust air of 63°F for average March outdoor

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1 ASHRAE Handbook and Product Directory, Fundamentals Volume, 1981, p. 21.01

2 Latta, J. K., "Walls, Windows, and Roofs for the Canadian Climate," Special Technical Publication No. 1, Division of Building Research, Research Council of Canada, Ottawa, 1973.

3 Anderson, L. O., "Condensation Problems: Their Prevention and Solution," FPL 132, Forest Products Laboratory, U.S. Dept. of Agriculture, Madison, WI, 1972.

conditions. This is only 2°F below the average March outdoor dry-bulb temperature, which could result in periodic condensation in the walls. If the indoor air temperature were maintained at 75°F the indoor relative humidity would be about 66 percent, or a relative humidity of 79 percent for an indoor temperature of 70°F.

Using the procedure just described, the prevailing indoor relative humidity and dew-point temperature can be predicted for various ventilation rates of outdoor air at selected winter conditions. The calculated results are summarized in the following Table A-1 for average March weather in Pensacola.

Table A-1. Required Ventilation Rates for March

Ventilation Rate ACH	Dew Point* of Exhaust Air, °F	Relative Humidity of Indoor Air, % Indoor Dry Bulb Temp.		
		75°F	70°F	65°F
1.0	53	46	55	65
0.5	56	52	61	73
0.2	63	66	79	94

*Average March Dew Point of Outdoor Air, 50°F, assumed for these calculations.

These results, compared with the average winter weather data, suggest that a ventilation rate of 0.5 ACH with outdoor air would control indoor relative humidity adequately from November through March in Pensacola, provided indoor air temperatures were kept at 70°F, or above. The conditions at 65°F dry-bulb indoors and 0.5 ACH would be conducive to accelerated mildew and mold growth. The rise in indoor relative humidity that accompanies a lower indoor dry-bulb temperature emphasizes the need for balanced heat distribution in the various rooms of the houses.

During the day, most of the moisture released in a residence would occur in the bathrooms, kitchen, dining room, and living room, but at night a major part of the moisture release would occur in the bedrooms. A sedentary adult releases about 0.1 lb/hr of moisture by respiration in an ambient temperature of 70°F. Thus a family of four adults would release about 0.4 lb/hr of moisture in the bedrooms at night. This rate is about 60 percent of the 24-hour average cited above for a typical family. The three bedrooms in the Corry units do not comprise more than 40 percent of the house volume. Thus the problem of moisture dissipation in the bedrooms, if the doors were closed, would probably be more serious than in the house as a whole, unless good recirculation of bedroom air was provided. The data in Table 9 indicate an air change rate of only 0.1 ACH in the bedrooms of Corry unit 2363A with the doors open and the circulating fan off. The air change rate in the bedrooms was even lower with the bedroom doors closed. It was found that the air change rate in the bedrooms with the doors open and the furnace fan operating would have been close to the whole-house average of 0.2 ACH. However, the above calculations show that even a 0.2 ACH is inadequate to prevent excessively high indoor dew-point temperatures and relative humidities in winter.

It is recommended that a minimum winter ventilation rate of 0.5 ACH be provided in the Corry units. It should be noted that only one of the 25 units for which air infiltration data are reported in Table 12 had an infiltration rate in excess of 0.5 ACH. Also, proper balance of the air distribution system must be maintained so that all rooms receive their proportional share of heated air.

The most efficient way to provide a reliable winter ventilation rate of 0.5 ACH is to install a fresh air duct originating in the attic or above the roof and connected to the intake side of the furnace fan. This duct would have to contain a manual or automatic damper which could be closed during the months of April through October because too much outdoor air adds significantly to the air-conditioning load and makes it more difficult to control indoor relative humidity in the summer months.

In addition, steps need to be taken to assure adequate recirculation of indoor air from the bedrooms at night. This can be achieved most economically by leaving all bedroom doors partially open at night, leaving the heater fan running at all times, by undercutting the bedroom doors, or by installing a louvre in the door or in the wall adjoining the hall. These methods entail some loss of privacy. At somewhat greater expense, the hallway ceiling could be furred down a few inches to enclose connected return ducts or to serve as a return plenum. This solution would provide greater privacy in the bedrooms. In addition, the temperature in the bedrooms should be maintained at 70°F or higher. If lower temperatures are maintained consistently during the winter, the ventilation rate would need to be increased accordingly.

APPENDIX 2

SUMMER RELATIVE HUMIDITY CONTROL

Indoor conditions of temperature and relative humidity that are comfortable and that inhibit mold and mildew growth cannot be attained by ventilation with outdoor air in the Pensacola climate during the summer months. An infiltration or ventilation rate of 0.2 to 0.3 ACH is required to maintain the CO, CO_2 and O_2 levels within the ASHRAE minimum requirements for a family of four to six persons. However, the introduction of outdoor air adds to both the air-conditioning load and the difficulty in maintaining a suitable indoor relative humidity. Therefore, it should be kept at a practical minimum in hot, humid weather.

An air-conditioning unit controlled only by a dry-bulb thermostat cannot always provide satisfactory indoor relative himidity in humid climates. In cool or moderately warm weather with high outdoor dew point (during or after showers) the thermostat does not require sufficient operation of the conditioning unit to remove the high moisture content of the air and does not maintain a suitable relative humidity. This could be an especially serious problem in the bedrooms of the Corry units at night. Because of the relatively high moisture release in the bedrooms at night, and because the lower nighttime outdoor dry-bulb temperature would typically require less operating time for the air conditioner, good air recirculation from the bedrooms is especially important. The same methods suggested above for adequate recirculation of bedroom air in the winter will function for summer air recirculation.

The conventional method for obtaining simultaneous control of dry-bulb temperature and relative humidity with an air conditioning unit is to use a humidistat and thermostat in parallel for control. When the air conditioning unit is operating on the humidistat it is often necessary to provide reheat in the discharge air to prevent overcooling of the house. Such a control method usually increases the total energy usage of the equipment. An alternative method for humidity control is to modify the air conditioning equipment to increase its dehumidification capacity without a significant increase in energy use. This can be accomplished in many instances by reducing the air-flow rate across the refrigeration coil, reducing the sensible cooling capacity of the equipment, but increasing the coil's dehumidification capacity. The two approaches should be tried on a pilot basis in a few houses before deciding which is the most practical cost-and energy-effective for the entire housing development.

In general, it is recommended that the indoor relative humidity be kept below 65 percent to minimize the problems of mold and mildew.

APPENDIX 3

WINDOW REPAIR RECOMMENDATIONS

(Quoted from report of Architectural Testing, Inc., Two Interchange Place, York, Pennsylvania 17402)

Windows are believed to be series 200 by ALENCO, 616 West Carson, P.O. Box 3309, Bryan, Texas, 77801, (713) 779-7770.

Glazing leaks. Loose glazing at fixed light; all test samples exhibited glazing leaks at the fixed lights. Ideally, the fixed-light glass should be removed and reglazed using Schnee-Morehead ACRYL-R^{R} backbedding compound, or an equal compound which meets AAMA 805.3 Specification for Bonding Type Backbedding Compound for use with Architectural Aluminum. Another approach would be to apply an exterior cap bead of GE 1200 silicone sealant at the glass-to-metal joint. This would seal the leaks but not offer equal structural strength.

Weather seal shrinkage. The original type extruded vinyl (PVC) weather seal is available from the window manufacturer. Due to the use of a custom extruded weather seal, replacement with any other material is not feasible.

Sill corner leaks and overflow. All window sills should be thoroughly cleaned, debris removed to allow for sill drainage. Sill corners should be resealed with Schnee-Morehead ACRYL-R^{R} no. 5504 Seam Sealer or equal, tested to AAMA 803.3 Specification for Narrow Joint Seam Sealer Compound for use with Architectural Aluminum.

In addition, it is recommended that the screen frames at the sill be notched at the location of the window weep holes so that the screen does not block the weapage from the window channels.

APPENDIX 4

PAINTING GUIDE SPECIFICATION FOR CONCRETE MASONRY AND BRICK WALLS [1]

By Dr. Paul G. Campbell, Gapland, Maryland 21736

A.4.1 Surface preparation. Remove all loose, peeling, blistering paint and accumulated surface contaminants. Brush-off abrasive blasting or high pressure water spray is the preferred method of paint/contaminant removal. Make any necessary masonry repairs and/or replacements, or repointing to any deteriorated masonry or mortar joints exposed during cleaning. All cleaned surfaces should have an ASTM D 659 chalk resistance rating of 8 or greater and no visible areas of loose paint prior to approval for paint application.

A.4.2 Supplemental Surface Preparation. Where extensive surface cracks, deteriorated masonry and mortar joints or other surface voids are revealed by paint removal, the masonry substrate must be restored. Surface bonding mortars, consisting of 0.5-1 percent short alkali-resistant glass fibers in mortar may be troweled on the surface. Normally, the mortar thickness is 1/8-1/4 inch. The surface bonding mortar may be modified with small amounts stearate or an acrylic resin for additional water repellency. Also, proprietary acrylic resin-modified block fillers (mortars), e.g., Thoroseal, 2/ may be applied thinly over the surface by trowel, squeegee, or brush to cover surface defects. Cement stucco application would also be a viable treatment for surface restoration. Addition of selected alkali resistant pigments to the stucco would eliminate the necessity of additional paint application.

A.4.3 Paint and Application. The paint applied to the masonry or restored substrate performs an esthetic function and the unpigmented restored substrate should be painted to blend into the color scheme of the surrounding installation. Other characteristics of the paint to be used should be high water repellency and a high permeance to water vapor so that moisture cannot get "trapped" in the walls. To meet these performance characteristics, the paint material should be a 100 percent acrylic emulsion exterior paint conforming to the requirements of Federal Specification TT-P-19. A certified test report showing that the paint was acrylic and met all specification requirements shall be furnished by the contractor. All previously painted masonry surfaces where the base material is exposed, either before or after cleaning, shall be thoroughly primed with the acrylic emulsion exterior paint. The

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1 For more detailed guidance, consult, "Paints and Protective Coatings," NAVFAC MO-110, June 1981.

2 Use of a trade name does not imply endorsement of the particular product. Other products may be on the market which also have similar compositions and performance.

finish coat shall be one coat of the acrylic emulsion exterior paint applied to the properly cleaned and primed surface. Apply priming material evenly by brush. Finish-coat material may be applied by brush, roller or spray. The paint application rate shall conform to guidance given by the specification and/or manufacturer's recommendations. Inspection of paint application shall be by Base personnel.

It may be desirable to pre-evaluate innovative systems (e.g., masonry, surface bonding mortar, paint) by conducting laboratory tests according to ASTM Standard E 514-74. Such tests should be used for screening purposes only, as results of tests on freshly applied coatings may not be truly indicative of performance after extended in-service exposure to the severe climate conditions prevailing in Pensacola.

A.4.4 Cleanup. Remove all paint where it has splashed or scattered. Damage to Government property or structures shall be restored to their original condition at no additional cost to the Government.

A.4.5 Altervative Renovative Surfacing Systems. Innovative siding systems may also be considered. However, these systems are more expensive than renovation using paint, and repainting will eventually be part of the maintenance process. For example, vinyl siding may be applied to the unrestored masonry substrate by the use of furring strip. As there is a continuous moisture problem in Pensacola, adequate ventilation behind the siding must be ensured to prevent moisture build up in the walls. Another possibility is the Dry-Kit 2/ siding system which consists of polystyrene insulation panels covered with fiber glass matting and a textured coating. The panels maybe applied to the unrestored substrate by the use of furring strips, adhesive, or mechanical fasteners. Installation costs for this system is around $5.00/square foot and a more impact resistant system is around $7.00/square foot. 3/ Part of the high installation costs would be justified on the potential energy savings with the added insulated panels. Figure 19 on page 59 depicts a similar system.

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2 Ob. Cit.

3 These systems were applied at Tobyhanna Army Depot, PA. The cost quoted were received in private communication from Mary E. McKnight, NBS, April 1983.

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